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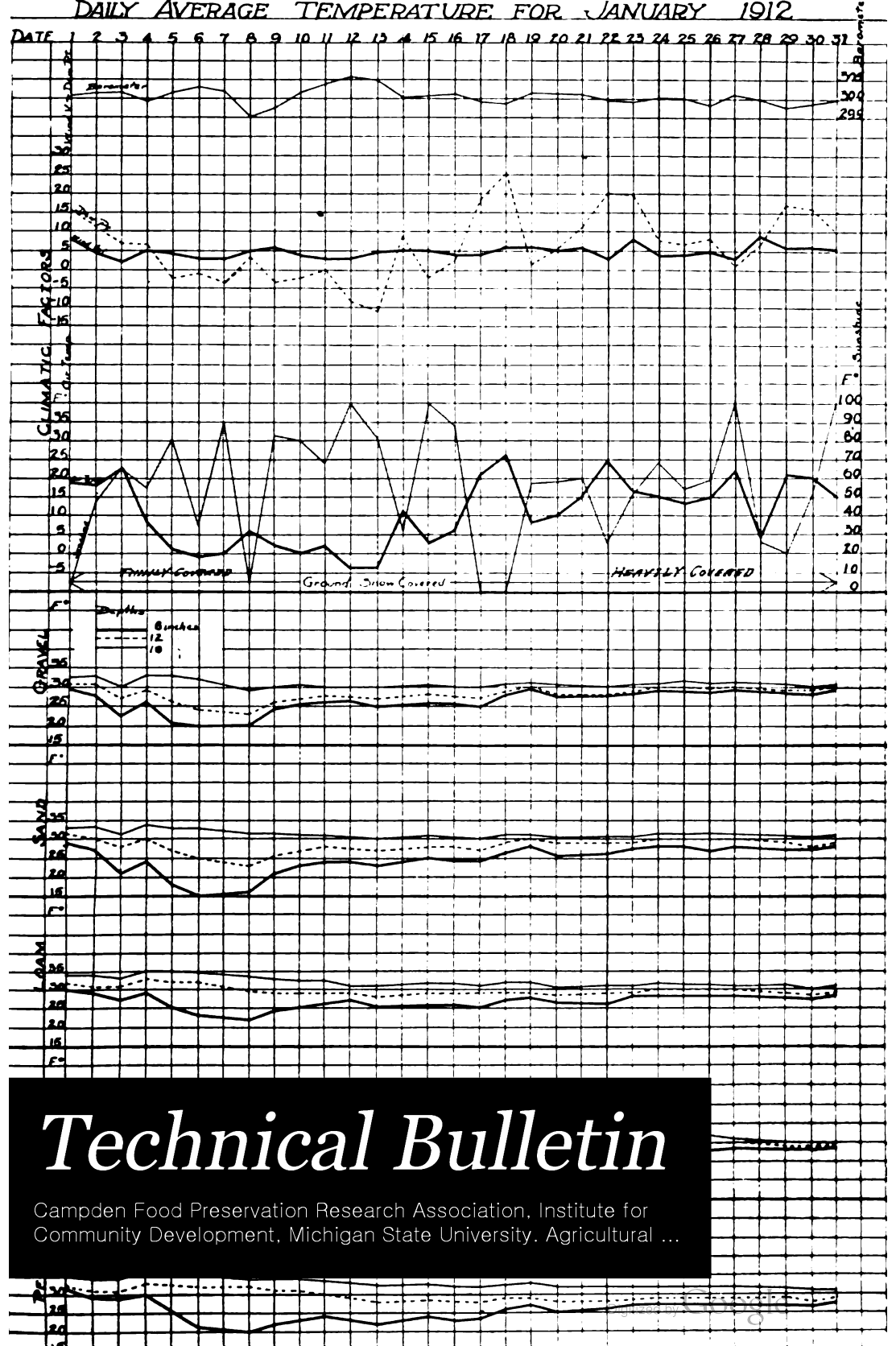


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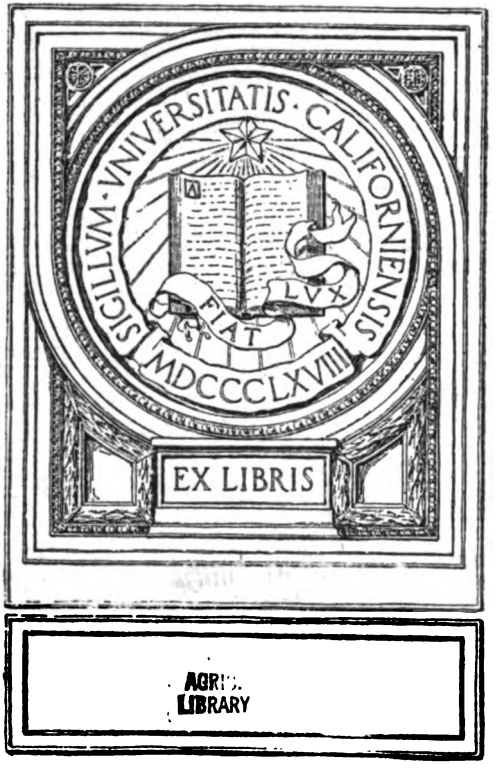


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TECHNICAL BULLETIN NO. 17 FEBRUARY, 1913

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EXPERIMENT STATION

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DIVISION OF SOILS

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# AN INVESTIGATION OF SOIL TEMPERATURE AND SOME OF THE MOST IMPORTANT FACTORS INFLUENCING IT.

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BY
GEORGE J. BOUYOUCOS

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EAST LANSING, MICHIGAN
1913

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## FORWORD.

For nearly two years Dr. Geo. J. Bonyoucos has been making a study of some of the factors affecting the temperature of soils. A description of some of his work and the conclusions drawn therefrom form the subject matter of this bulletin.

This work has been deemed important for the reason that some of the conclusions usually accepted concerning soil temperature have not been satisfactory—have not seemed to accord with observed facts. Apparently these conclusions have been drawn, in part at least, from analogy, and in part without giving due weight to other physical factors involved. Working with facts rather than from analogy, and giving to various factors their proper values the general problem becomes clearer and the conclusions are in accord with the facts of soil behavior.

JOS. A. JEFFERY,
Soil Physicist.

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## INTRODUCTION.

Soil temperature is one of the essential limiting factors of plant growth. It affects the three most important functions in the soil: the biological, the chemical, and the physical, and thereby controls to a very large extent, the productive power of a soil.

The biological effects at once become evident when it is considered that all life depends not only for its progress, but also for its existence upon soil temperature. Indeed, the germination of seed, the maximum growth of plants, the multiplication and functions of the lower organisms, the taking up of food by plants through osmotic processes, etc., depend to a very large extent, upon soil temperature. Moreover, all these biological processes attain their maximum end not at the minimum, nor yet at the maximum, but at the optimum temperature, which optimum temperature is different for the various kinds of life.

To preceive the chemical role that temperature plays in the soil it will suffice merely to mention that it is a great accelerator of all chemical reactions: it influences the solvent action of water; it influences the velocity of the reaction; it increases the osmotic pressure of the solution; it favors the formation of nitrates; it hastens the weathering of mineral material and the decomposition of organic matter.

From the physical standpoint temperature affects many processes in the soil: it causes a movement of the soil moisture and of the salts due to the change in their surface tension and viscosity; it produces a movement of air on account of the change in pressure. A change in temperature also causes a disintegration of the rocks or soil material due to expansion and contraction.

These biological, chemical, and physical functions of soil temperature emphasize the great importance of the subject and the need for a thorough and extensive knowledge concerning it. Unfortunately our present knowledge of it is very limited. The reasons for this may be divided into two general groups: (1) We do not yet know absolutely the nature of heat and hence of the temperature; and (2) our present methods for measuring soil temperature are very unsatisfactory.

That our knowledge of the nature of heat is yet uncertain will be at once evident if the two views concerning it are considered. The static view considers heat as being a substance and designates it as caloric. The dynamic view, on the other hand, considers heat as a mode of motion; or as a measure of the internal energy of the molecules of the body. All bodies, it maintains, consist of molecules in a state of vibration and the energy of the motion of these molecules determines the temperature of the body; that a difference of temperature between two bodies merely means that a diffference exists in the energy of their molecules; and that this difference may be equalized with the lapse of time by radiation, conduction, and convection until

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equilibrium results. This dynamic theory of heat established by the experiments of Rumford, Davy, and Joule, has been the accepted view of modern physics, while the static theory has been entirely abandoned. Very recently, however, Callender suggests the idea that this old, discarded caloric theory may be right after all. He maintains that what we call heat and measure as heat, is merely the energy of heat, the heat itself may well be a substance that carries energy as a stream of water carries the energy that turns the mill-wheel.

These different views concerning the nature of heat go to show that after all we are not absolutely sure what heat is, of the laws governit, etc., even tho modern physics considered it one of its triumphs that it had demonstrated beyond doubt the nature of heat from the dynamic standpoint.

Undoubtedly by far the greater part of our limited knowledge of soil temperature is due to our unsuitable and unsatisfactory methods or instruments employed for its measurement or study. Until very recently, in fact in all the soil temperature studies that are on record, the mercury thermometers have been used almost exclusively as a means for the measurement of temperature. These instruments, altho in use in almost all scientific temperature investigations, are far from being very satisfactory for the measurement of soil temperature. One of their serious defects is the unequal length of their mercury bulbs, which gives rise to the difficulty of measuring accurately the temperature of the same depth of different soils. In the second place, if the stems are of the same length and the bulbs are placed at different depths, there will be unequal mercury columns exposed to the atmosphere, and thus, on account of the marked difference of temperature in air and soil, there will undoubtedly be an error introduced in the data.

Both these obstacles, however, could be eliminated or obviated to a very large extent by having thermometers made to order with the same length of bulbs and with the proper length of stems. But there are still other disadvantages connected with such instruments such as (1) their fragibility and consequently their unsuitability for long duration or permanent experiments; (2) their inconvenience for reading and consequently the errors that may arise due to the parallax; and (3) the adhering of the mercury column to the stem thus giving low or high readings.

Perhaps on account of these difficulties, and also because of the many other complex obstacles involved, the general subject of soil temperature has heretofore received comparatively little investigation. In fact, there is on record no extensive, thoro, and systematic investigation on the subject. Considerable work has been done on certain individual phases of the problem. The first and best scientific study of the subject has been done in Germany by Wollny and his associates. In no other country has the subject received much attention. In America the only important studies are the few practical observations made by King, and the recent work of Patten on heat transference in soils.

While the greater part of the past work is good so far as it goes, there is considerable which is rather inferior, the results of which have led to many erroneous and faulty conclusions. Many of these unsound conclusions have been deducted from short duration experiments; from only one phase of the subject; and from results which were obtained

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under too artificial a condition. The subject of soil temperature is a most complex problem, and in order to arrive at proper, definite and valid conclusions, it must be investigated from all standpoints, and as far as possible, under both natural and controlled conditions. That the subject demands a broad study for arriving at definite and sound conclusions, is evidenced by the great number of factors which affect or influence it. These factors may be divided into two general groups, intrinsic and external. The intrinsic factors are those contained in the soil, such as specific heat, specific gravity, heat conductivity, radiation, absorption, moisture content, organic matter content, concentration of solution, evaporation, nature of surface, topographic position, etc. The external factors consist of the meteorological elements, chief of which are the air temperature, sunshine, barometric pressure, wind velocity, dew point, humidity, precipitation, etc. Each one of these general groups may be subdivided into two parts, one part tending to impart heat to the soil and thereby raise its temperature, and the other part tending to take away heat from the soil and thereby lower its temperature. These opposing factors are in operation all the time, but some predominate over the others at different seasons of the year. A temperature record, therefore, taken at any time under field conditions may be considered to be the resultant or summation of the effects or forces of these opposing or contesting factors.

In view of the paramount importance of the subject, of our limited knowledge, and the uncertainty of many conclusions concerning it, it has seemed essential and justifiable to undertake an investigation of the problem. Such an investigation, however, to be of the greatest value should be conducted more thoroughly, extensively, and systematically than it has been heretofore. Accordingly the policy followed has been the following: First, to investigate individually or in combination, many of the chief soil factors affecting the soil temperature; second to study the effects of these various factors on the temperature of the soil under field conditions; and third, to ascertain the relationship between soil temperature and the different meteorological elements.

By attacking the problem from this broad standpoint, and by using the same kinds of soils for the study of many of the soil factors, it was thought that the work would yield more definite and conclusive knowledge, and it would also enable us to form a better and more definite idea as to the magnitude of these respective temperature factors, also which ones are most predominant and play the greatest role in determining or controlling the warmth of the soil.

In the present bulletin are reported the results of the completed laboratory experiments and the results of only one year of the field experiments. It is hoped that the latter experiments will be conducted through a number of years and that the data will be reported from time to time.

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## SPECIFIC HEAT OF SOILS.

### OBJECT AND METHOD OF EXPERIMENTATION.

Specific heat is defined as the number of calories needed to raise one gram of a substance 1° C. The specific heat of soils has received attention from various investigators at different times, notably from Pfaundler,[1] von Schumacher,[2] v. Liebenberg,[3] Lang,[4] Ulrich,[5] and Patten.[6] The results obtained by these investigators for the chief soil types are given in the following table:

TABLE 1.—SPECIFIC HEAT OF SOILS.

| | Pfaundler. | Schumacher. | v. Liebenberg. | Lang. | Ulrich. | Patten. |
|---|---|---|---|---|---|---|
| Sand | 0.203 | .128 | .272 | .196 | .191 | .184 |
| Loam | 0.208 | .205 | .188 | .214 | .208 | .205 |
| Clay | ..... | .190 | .161 | .233 | .224 | .156 |
| Peat | 0.507 | ..... | .301 | .477 | .443 | ..... |

It is evident that the specific heat of any one type of soil, as found by the different experimenters, is significantly different. The reason for such disagreement is undoubtedly due (1) to the difference in composition of the material, even tho it is designated by the same name; (2) to the different methods employed; and (3) to the difference in technic in the manipulation.

Since it was necessary to know the exact specific heat of the particular types of soil which were to be used for the various phases of soil temperature study, and since such knowledge could not be obtained from the above data, it was deemed essential to ascertain it directly.

There are a large number of methods employed for specific heat determination of solid materials, but they are all based upon the method of mixtures. While numerous as are these methods, they are all defective; an error enters into all of them due to the loss of heat during the operation.

The method employed in the present study was devised in the course of the investigation and was adopted in preference to a large number of others that were tried. This method consists in wrapping a definite weight of soil in a known weight of filter paper, tying the latter with a very fine thread, then suspending it in a heater at a temperature of about 97° C. After the soil remained in the heater for two or more hours and had attained a constant temperature it was dropped at once into the calorimeter and stirred vigorously until the maximum temperature was indicated on the thermometer. This temperature was usually obtained in about one minute. The filter paper upon coming in con-

(1) Ann. d. Physik u. Chemie 5. Reihe, 9 Bd. (1866): 102–135.
(2) Die Physik Des Bodens, Berlin (1864): 245.
(3) Habilitationschrift Halle 1875.
(4) Forsch. a. d. Geb. d. Agrikulturphysik Bd. 1.: 109.
(5) Forsch. a. d. Geb. d. Agrikulturphysik Bd. 17: 1.
(6) Bul. 59, U. S. Dept. of Agri., Bureau of Soils. 1909.

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tact with the water would immediately break up and allow the soil contained to mix with the water and thus give up its heat more rapidly than if it had been enclosed in a water-tight vessel as has been done by several investigators, which process delays the reaching of the maximum point on account of the poor heat transference of the soil material. Both the free soil and the filter paper upon becoming wet increased the temperature, but this increase was deducted from the final calculation by ascertaining it in a separate experiment wherein was used the same amount of soil, filter paper, and water as in the regular determinations and having them at about the same temperature (25° C.) The temperature increase due to wetting of the various dry soil powders is considerable, as will be shown subsequently, and unless it is taken into consideration in the final calculation of the results the latter will be altogether too high, especially for certain soils. The size of particles also influences the heat generation due to wetting, consequently in all the different kinds of soils except the gravel, whose specific heat was determined, the same size of particles was used, i. e., those which could pass thru a 40 sieve mesh.

In the determination of the specific heat of the peat it was found that this material would not settle to the bottom of the calorimeter and consequently considerable heat would be lost before the cover of the calorimeter was put on and the stirring process begun. To overcome this difficulty and thereby eliminate the error, a piece of copper was placed with the soil which would cause the soil to immediately fall to the bottom of the calorimeter. The specific heat or water equivalent of this copper piece being known would be deducted from the final calculation of the results. In all these specific heat determinations the temperature was taken by a Beckmann thermometer, and the specific heat apparatus employed was of McCall's type.

### SPECIFIC HEAT OF SOILS BY EQUAL WEIGHTS.

The following table represents the specific heat of the different types of soil as determined by the above method, and the different individual data necessary for the calculation of the same. The mechanical analysis of these different types of soil is shown on table 18a.

This table shows that the specific heat of the different types of soil varies very little, that of the quartz sand is the lowest, followed in order by gravel, clay, loam and peat. The specific heat of the latter soil as determined in this investigation, is very interesting because it is just about half as great as that given to it by some other investigators.

In the above table is also shown the amount of heat generated by the different soils when wetted. It will be seen that this quantity of heat is considerable and becomes greater as the organic matter of the soil increases. In this respect it follows the same law as the specific heat.

The slight difference in the specific heat of the different soils, as shown above, points to the important conclusion that this property plays an insignificant part in the heat relationships of these soils.

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TABLE 2.—SPECIFIC HEAT OF SOILS BY EQUAL WEIGHTS.

| Name of soil. | Number of trials. | Grams of soil. | Grams of water. | Temperature of water in C.° | Temperature of soil in C.° | Final temperature in C°. | Water equivalent of calorimeter. | Calorimetric system. | Heat due to wetting soil and paper C.° | Specific heat. | Ave. Specific heat. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sand | 1 | 20 | 180 | 19.65 | 96.70 | 21.35 | 11 | 191 | .170 | .1934 | ..... |
| | 2 | 20 | 180 | 20.90 | 95.80 | 22.55 | 11 | 191 | .170 | .1925 | .1929 |
| Gravel | 1 | 20 | 180 | 19.30 | 95.10 | 21.10 | 11 | 191 | .232 | .2017 | ..... |
| | 2 | 20 | 180 | 22.15 | 96.10 | 23.95 | 11 | 191 | .232 | .2065 | ..... |
| | 3 | 20 | 180 | 18.55 | 95.40 | 20.40 | 11 | 191 | .232 | .2053 | .2045 |
| Clay | 1 | 20 | 180 | 18.30 | 96.50 | 20.45 | 11 | 191 | .526 | .2025 | ..... |
| | 2 | 20 | 180 | 19.95 | 96.40 | 22.10 | 11 | 191 | .526 | .2072 | ..... |
| | 3 | 20 | 180 | 18.40 | 96.90 | 20.60 | 11 | 191 | .526 | .2081 | .2059 |
| Loam | 1 | 20 | 180 | 20.52 | 96.30 | 23.05 | 11 | 191 | .826 | .2197 | ..... |
| | 2 | 20 | 180 | 20.05 | 96.20 | 22.55 | 11 | 191 | .826 | .2146 | ..... |
| | 3 | 20 | 180 | 21.89 | 97.10 | 24.35 | 11 | 191 | .826 | .2120 | .2154 |
| Peat | 1 | 20 | 180 | 21.92 | 95.40 | 27.85 | 11 | 191 | 4.04 | .2521 | ..... |
| | 2 | 20 | 180 | 20.70 | 95.00 | 26.70 | 11 | 191 | 4.04 | .2521 | ..... |
| | 3 | 20 | 180 | 21.95 | 95.90 | 27.90 | 11 | 191 | 4.04 | .2534 | .2525 |

## SPECIFIC HEAT OF SOILS BY EQUAL VOLUMES.

The next question that arises is what is the specific heat of these same soils when considered from the standpoint of equal volumes. Practically speaking it is the specific heat by equal volume that is important from the agricultural standpoint and not the specific heat by equal weight. In the field it is the depth or volume and not the weight that is heated that is important to the plant.

The specific heat of a soil by equal volume can be obtained by multiplying its specific gravity by its specific heat by weight. The results obtained by this process are shown in the following table:

TABLE 3.—SPECIFIC HEAT OF SOILS BY EQUAL VOLUMES.

| Name of soil. | Specific gravity. | Specific heat, equal weight. | Specific heat, equal volume. |
|---|---|---|---|
| Sand | 2.664 | .1929 | .5093 |
| Gravel | 2.707 | .2045 | .5535 |
| Clay | 2.762 | .2059 | .5686 |
| Loam | 2.558 | .2154 | .5507 |
| Peat | 1.755 | .2525 | .4397 |

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It will be seen that the difference in the heat capacity considered from the equal volume standpoint is also small in magnitude between the different soils, but that the order is very different from that of the specific heat by equal weights. In the latter case peat has the highest specific heat and is followed in order by loam, clay, gravel, and finally by sand; while in the case of equal volumes peat has the lowest specific heat with sand, loam, gravel, and clay coming next in respective order.

### INFLUENCE OF MOISTURE ON SPECIFIC HEAT OF SOILS.

In field conditions the specific heat of soils by equal volume is also unimportant because the different soils in their natural condition possess different amounts of water on account of their different water holding capacity, and water as will be shown, is one of the predominant controlling agents of soil temperature. With the exception of hydrogen gas, water possesses the highest heat capacity of any other substance. In comparison with that of the dry soils, it is five times greater. This is very significant because it means that it requires five times as much heat to raise the temperature of a unit quantity of water to one degree as is necessary for a unit weight of soil. The different types of soil possessing markedly different water contents, will have entirely different specific heats than those shown above.

To correctly value the tremendous influence that soil moisture has upon soil temperature, this moisture must be determined by volume. Such determination, then, gives a true comparison of the amount of water the different soils may hold under natural condition, which condition from the agricultural or practical standpoint is the most important and satisfactory.

TABLE 4.—EFFECT OF MOISTURE ON THE SOIL TEMPERATURE.

| Name of soil. | Wt. of a cu. ft. lbs. | Percent moisture. | Specific heat of soils. | Rise of temp. of dry soils by 100 heat units. | Rise of temp. of moist soils by 100 heat units. |
|---|---|---|---|---|---|
| April 3, 1912: | | | | | |
| Gravel | 109.2 | 10.45 | .2045 | .009854°C | .006520°C |
| Sand | 102.7 | 16.96 | .1915 | .011170 | .005876 |
| Loam | 72.93 | 40.7 | .2154 | .014010 | .004848 |
| Clay | 76.35 | 29.16 | .2059 | .013990 | .005790 |
| Peat | 36.76 | 256.5 | .2525 | .023740 | .002127 |
| November 4, 1912: | | | | | |
| Gravel | 109.2 | 6.91 | .2045 | .009854 | .007365 |
| Sand | 102.7 | 3.78 | .1950 | .011170 | .009208 |
| Loam | 72.93 | 38.12 | .2154 | .014010 | .005056 |
| Clay | 76.35 | 26.81 | .2059 | .013990 | .006079 |
| Peat | 36.76 | 135.5 | .2525 | .023740 | .003725 |

The moisture content by volume of all the types of soil in which the specific heat has already been considered, has been determined in the following manner: The weight of a cubic foot of each soil was determined in the regular way. Their moisture content was found under the same field conditions many times during the year: in the early spring before they began to thaw, in the middle of the summer, in the

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late fall when they began to freeze, after a long drought, and immediately after a heavy rain. The percentage of the moisture content found under this variety of conditions multiplied by the weight of a cubic foot of soil gives the amount of water contained in that volume of soil. Knowing the specific heat of water, the influence that the moisture content exerts on soil temperature can readily be calculated. The table below represents the number of degrees Centigrade that 100 heat units will raise or lower the temperature of a cubic foot of the different types of soil.

A careful examination of the table reveals many striking and significant facts. It shows (1) that on account of the great difference in the weight of a cubic foot the influence of the specific heat of equal weight is offset so that the peat which possesses the greatest heat capacity but the lowest weight has its temperature raised about twice as much as that of the sand and gravel which have the lowest specific heat but the greatest weight; (2) the differences in the moisture content are so great in the different types of soil that the influence of the weight of the soil on the temperature is again offset or overshadowed so that the peat which in the dry condition is about twice as warm as the sand or gravel, is now from two to three times colder than the latter soils. This latter fact was actually obtained also in field conditions. The peat for instance, remained frozen in the spring about 10 days longer and in the fall it usually froze after the other soils had frozen. All these facts lead to the important conclusion that while the specific heat as well as the weight play some important part on the ultimate soil temperature, and especially on its ascent and descent, their influences are minimized and indeed overshadowed by the tremendous influence of water with its great heat capacity. Hence it cannot be determined with certainty what the rising or lowering of temperature will be of any particular group of soils merely from the specific heat and weight of a cubic foot, unless the water content also is known.

## HEAT CONDUCTIVITY OF SOILS.

### OBJECT AND METHOD OF EXPERIMENTATION.

Heat conductivity is defined as the quantity of heat in calories which passes across a cube of unit edge (1 cm), in unit time (1 second), under a uniform temperature gradient of one degree centigrade per centimeter.

Heat conductivity is one of the three modes of heat propagation, the other two are radiation and convection. These three modes of heat transmission are independent of and essentially different from each other. In the process of conduction the heat is transferred from one body to another, or from one part of the body to another part by contact, or by means of the molecules; while in radiation the heat is propagated as a free-wave motion in the ether without permanently affecting the intervening space between the radiating body and the body receiving the radiant energy. The process of convection, on the other hand, takes place chiefly in liquids and gases, where heat is conveyed

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or transmitted by the interchange of the unequally heated currents of these liquids or gases.

Heat transference in soils has already received considerable attention from investigators. Especially important is the work on the subject of [7]Haberland, v. [8]Littrow, [9]Pott, [10]Wagner and [11]Patten. The method of study of all these investigators consisted in determining the heat conductivity of powders of soils of different sized particles in dry, moist, and wet condition, and with different degrees of compactness. The materials were placed in a well-insulated vessel, one side of which consisted of some metal which was brought in contact with a constant source of heat. The results obtained by Haberland, v. Littrow, Pott and Wagner are only relative or qualitative, while those of Patten are quantitative.

While the results of all these investigations are valuable and interesting, they have only a theoretical and suggestive value, because they were all obtained under artificial conditions. It is a well-known fact that it is practically impossible to imitate in the laboratory the absolute condition which the soil possesses in the field. The heat conductivity is noticeably influenced by many factors, especially by texture, structure, and moisture content. When one of these factors is changed the others also are changed. Under field conditions, the soil, from long standing, has given these factors an opportunity to come to equilibrium and, therefore, it will possess a certain rate of heat transmission at any given time. In the laboratory, however, these factors cannot be brought into equilibrium, and hence the heat conductivity measurements under this condition have mostly a suggestive and theoretical value, however, qualitative or quantitative they may be.

In order that data on the heat transmission in soils may be of practical value, they must be obtained under natural field conditions. There are many difficulties that arise or are involved in such operations which tend to minimize the importance of the results. In the first place, the different soils possess different shades of colors and would tend to absorb heat unequally and, therefore, would be heated unequally. In the second place, the different soils contain different amounts of moisture and different powers of capillary rise of water, hence there will be unequal evaporation of water on the surface, and consequently a different rate of heating.

### HEAT CONDUCTIVITY OF NATURAL SOILS UNDER LABORATORY CONDITIONS.

The next best way to study the heat conductivity which would yield data of practical as well as of theoretical value, would be to cut cores of soils at different seasons of the year, depending upon the meteorological elements which would bring the soils under the different conditions of moisture, texture and structure, and thus measure the heat conductivity of these cores of the different kinds of soils under controlled laboratory conditions. In the present investigation, that is just what

(7) Wissenschaftl. praktische Untersuchungen auf dem Gebiete des Pflanzenbaues. Wein 1875.
(8) Sitzungsber. d. k. Akademie d. Wissenschaften 2, Abteil, Wien 1875. Januarheft.
(9) Landw. Versuchs-Stationen Bd. XX: 273 u. f.
(10) Forsch. a. d. Geb. d. Agrikulturphysik Bd. 6:1 u. f.
(11) Bulletin 59, Bureau of Soils, U. S. Department of Agriculture.

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was attempted. The method of operation was as follows: Four plates of iron 8 inches long, 7 inches wide, and ⅛ inch thick, with their front and opposite edges sharpened, were pressed or bored into the different types of soil—which types were placed one year before in adjacent wooden boxes 3 x 3 x 3 ft., without top or bottom, as will be explained later—so as to form a square. The soil around the outside of the plates was then removed to its full depth. The plates came out and left the core of the soil standing. A wooden box 8 inches deep, 6 ¾ inches wide, and 1 inch thick, was placed over this core until the top soil was even with the upper side of the box. Next a copper plate was fitted on this side of the box which came in intimate contact with the top of the soil. The bottom of the core was next severed from the ground with a sharp knife, then smoothed and kept in place by a wooden cover. This whole operation, i. e., driving the plates into the ground, placing the box over the core, severing the core from the ground, was done with the greatest possible care so that the structure of the soil core may not be disturbed. Precautions were also taken to secure the core 6¾ inches in diameter so that any slight friction on the sides would not affect its structure.

The box which contained the core of soil consisted, as already said, of four wooden sides, one wooden bottom, and one copper top. Before it was placed over the soil, it was boiled in paraffin. Along the center of the lengthwise side, 7 holes were bored one inch apart to admit thermometers.

Four cores of soil were taken, one from sand, loamy, clay, and peat respectively. No core was taken of the gravelly soil since its texture would not permit the plates being driven into it without materially disturbing its structure.

Mention has been made that the top of the core of each soil was smooth and came in contact with the copper plate. To be more certain of this a layer of moist quartz sand was placed over each core before covering it finally with the copper plate. There could now be no doubt of an absolutely perfect contact. Each box was then made air tight by paraffin so that there would be no evaporation. The soils were allowed to remain in the room for several hours to attain the same temperature, before the study of their heat transmission was commenced.

The copper plate end of the box was placed up against the copper side of a tank the water in which was kept at the constant temperature of 33.5° C by means of an electrical arrangement shown in the diagram I. A is a tank filled with water, C is a 32 candle power electric light by means of which the water is heated. The bulb is connected to the circuit breaker or magnet D which in turn is attached to the thermostat E. F is a stirring fan run by the motor G. H is a stand upon which the soil box rests. This stand is brought as close to the tank as possible and fastened to it by means of a wire, while the soil box is pressed firmly against the side of the tank by means of the screw I.

As soon as the box came in intimate contact with the source of heat, records of the rate at which the heat traveled through the soil were begun. The method adopted to measure this rate of heat transmission was to note the time when the soil box was brought to the constant source of heat also the time when the mercury column of each thermo-

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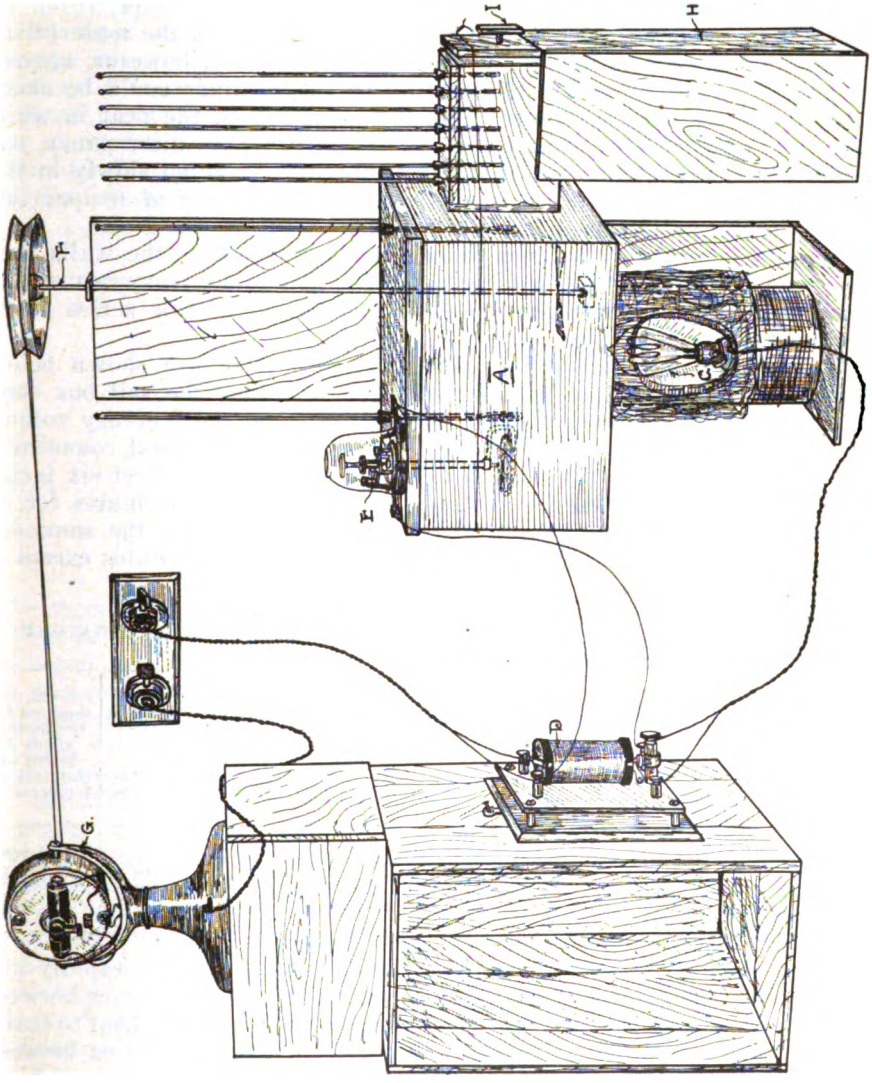


FIG. 1. HEAT CONDUCTIVITY APPARATUS.



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meter began to rise. The bulb of the thermometer was always in the center of the core or about 3 inches deep.

It will be evident that the results obtained in this way are qualitative and relative. No attempt was made to determine the heat conductivity in these cores of soils quantitatively because of the many errors involved as shown and enumerated by Patten; also because the quantitative results would not have any more significance either from the theoretical or practical point of view, as the state of the material experimented upon was unstable. The method adopted, however, appears to have been satisfactory and accurate as the readings could be checked within two to four minutes with the exception of the peat in which case the time varied as much as 10 minutes. This discrepancy was undoubtedly due to the fact that the temperature rose so slowly in this soil that it was difficult to note at once the beginning of temperature rise as easily as it was in the other soils.

There was probably no loss of heat from the box as the walls were over one inch thick and well paraffined. The room temperature also remained quite constant throughout the duration of this series of experiments.

The results obtained by the foregoing procedure are shown below. They represent the time that elapsed from the time the soil box came in contact with the source of heat until the time the mercury column of the thermometer at 7 inches from the surface of the soil commenced to rise. The data for the other six thermometers for the first six inches respectively, are left out for the sake of simplicity. The figures for all soils are the averages of four trials. These tests within the same soil did not vary from each other more than three or four minutes except in the peat.

TABLE 5.—HEAT CONDUCTIVITY OF NATURAL SOILS UNDER LABORATORY CONDITIONS.

| Name of soil. | Minutes required for thermometer at 7 inches to show rise in temperature. | Percent time required for thermometer at 7 inches to show rise in temperature. |
|---|---|---|
| Sand | 27 | 100 |
| Loam | 49 | 181.5 |
| Clay | 48 | 177.8 |
| Peat | 124.5 | 461.2 |

The results show that the sandy soil conducts heat most rapidly and is followed respectively by clay, loam, and peat. The difference between the sandy soil and peat is very great, the latter allowed the heat to travel thru it only one-third as fast as the former. The differences between the other two soils are very small and in favor of the clay.

### HEAT CONDUCTIVITY OF SOILS UNDER FIELD CONDITIONS.

The heat conductivity of the different types of soil under field conditions was determined by taking records every half hour by means of electrical resistance thermometers, which will be explained later, from

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seven in the morning till all the thermometers in the different depths or at any particular depth showed a rise in temperature. These different types of soil were contained in adjacent wooden boxes 3 x 3 x 3 feet, without top or bottom, and the soils had lain there for about a year so that they were well compacted by the different climatic agents. They were also covered with a thin layer of a sandy soil so that their insolation and evaporation were more or less equalized. These half-hour records were made at different periods of the season depending upon the condition of the ground, namely, after a long drought, immediately after a heavy rain, and a few days after the rain. By making these observations at different times under this variety of conditions, an idea was obtained as to the relative heat conductivity of these distinct kinds of soils in their natural state under field conditions. The data thus obtained are included below:

TABLE 6.—HEAT CONDUCTIVITY OF SOILS UNDER FIELD CONDITIONS.

| Date. | Depth. | Gravel. | Sand. | Loam. | Clay. | Peat. |
|---|---|---|---|---|---|---|
| July 27 | 6 in. | 4 hrs. | 4 hrs. | 6.30 hrs. | 6 hrs. | 9 hrs. |
| | 12 in. | 7 hrs. | 7 hrs. | 9.30 hrs. | 9.30 hrs. | ..... |
| August 5 | 6 in. | 4 hrs. | 4 hrs. | 6 hrs. | 5.30 hrs. | 8.30 hrs. |
| | 12 in. | 7 hrs. | 7 hrs. | 10 hrs. | 9.30 hrs. | ..... |
| August 26 | 6 in. | 4.30 hrs. | 4.30 hrs. | 7 hrs. | 6 hrs. | 9 hrs. |
| | 12 in. | 7 hrs. | 7 hrs. | 10.30 hrs. | 10 hrs. | ..... |
| August 27 | 6 in. | 4 hrs. | 4 hrs. | 6 hrs. | 5.30 hrs. | 9 hrs. |
| | 12 in. | 6 hrs. | 6 hrs. | 10.30 hrs. | 10.30 hrs. | ..... |
| September 23 | 6 in. | 4 hrs. | 4 hrs. | 6.30 hrs. | 6 hrs. | 9.30 hrs. |
| | 12 in. | 5.30 hrs. | 5.30 hrs. | 9 hrs. | 9 hrs. | ..... |

The figures in each case indicate the number of hours required for the heat to reach the two different depths from the time the air temperature began to rise. The commencement of the ascent of the air temperature was recorded by means of an air thermograph, which commencement usually took place from about four to six o'clock in the morning. The data show very conclusively that for both the 6 and 12 inch depths at every observation, the gravel and sand exhibit the greatest power of heat conductivity, followed respectively by clay, loam and peat; that the gravel and sand transmit the heat equally well, as do the loam and clay, but that the peat is the poorest heat propagator; also that the differences between the gravel and the sand are nil, between these and the loam and clay quite marked, while the difference between peat and any of the other soils is very great. One of the interesting points to be observed is the fact that the order as well as the magnitude of heat transmission in all these soils, is fairly constant, especially for the six inch depth for all the different observations.

Attention should be called to the perfect agreement in the order of heat transmission of these soils as measured under the field conditions and in the laboratory in the natural state. This interesting parallelism receives most important confirmation in the table below which contains the relative heat conductivity of these soils as determined under the field conditions on the same day that the cores of the respective soils were taken. The state of the material was the same and consequently the heat propagation under the two different conditions can be more truly compared.

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TABLE 7.—COMPARISON OF HEAT CONDUCTIVITY OF NATURAL SOILS UNDER FIELD AND LABORATORY CONDITIONS.

| Name of soil. | Percent of time required for temperature at 7″ to rise. Field conditions. | Percent of time required for temperature at 7″ to rise. Laboratory conditions. |
|---|---|---|
| Sand | 100 | 100 |
| Loam | 150 | 181 |
| Clay | 143 | 177.8 |
| Peat | 362 | 461.2 |

This table not only shows the close agreement in the order of the heat conductivity of the different types of soil as measured in their natural state under field and laboratory conditions, but also the more important fact that the magnitude in both cases is very much the same, except in peat in which case there is quite a disagreement.

It must be stated here that these different types of soil under field conditions were all covered with a very thin layer of a sandy soil so as to eliminate the factor of color. This layer of soil incidently performed several other functions, such as the prevention of formation of cracks on the top of the clay and loam soils, the tendency for equalizing the rate of evaporation among the different soils, etc. As a result, the heat conduction values obtained both under laboratory and field conditions approach more closely to the true heat conducting power of these soils. If these different soil types were not covered with the thin layer of the sandy soil the clay and loam would crack on the surface and these cracks would increase the rate of air diffusion and thereby decrease the difference in magnitude of conducting power between the sand and gravel and the clay and the loam.

In connection with the observations made on the heat conductivity of the different types of soil under field conditions, might be mentioned the similar studies made on cultivated, uncultivated and sod land. As will be stated later, the original object of this experiment was to ascertain the effect of these wholly different soil managements on the soil temperature. The temperature of these plots was taken by means of thermographs, the bulbs of which were placed at two different depths, 7 inches and 20 inches respectively. The results obtained are summarized below. The figures show the number of hours required for the heat to arrive at the 7″ depth, as indicated by the rise of the temperature, from the time the air temperature began to ascend.

TABLE 8.—HEAT CONDUCTIVITY OF FIELD SOILS UNDER CULTIVATED, UNCULTIVATED AND SOD CONDITIONS.

| Date. | Depth. | Uncultivated. | Cultivated. | Sod. |
|---|---|---|---|---|
| July 27 | 7″ | 4.0 hrs. | 5.0 hrs. | 5.0 hrs. |
| August 5 | 7″ | 4.0 hrs. | 5.0 hrs. | 5.30 hrs. |
| August 26 | 7″ | 3.30 hrs. | 5.0 hrs. | 6.0 hrs. |
| August 27 | 7″ | 4 hrs. | 5.0 hrs. | 5.30 hrs. |
| September 23 | 7″ | 3.30 hrs. | 4.30 hrs. | 5.0 hrs. |

It will be seen in every observation that the uncultivated ground allowed the heat to pass through it fastest and was followed in order by

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about one hour later by the cultivated, and by about one and one-half hours later by the sod land. Evidently the uncultivated ground is the best conductor of heat, the sod the poorest, while the cultivated lies intermediate. The greater moisture content in the cultivated and the vegetation on the sod plots undoubtedly affected the rate of heat transmission.

### HEAT CONDUCTIVITY OF SOILS IN THE DRY STATE.

Mention has been made that the heat conductivity of the foregoing types of soil was also studied in the air dry condition. The object of this investigation was two-fold: First, it was desired to ascertain the relative heat transmission of these soils in their water free state as compared with the transmission in their moist or wet state; and second, to see what relationship heat conductivity has to heat radiation of soils in the air dry condition.

This study was conducted in the same manner as the foregoing with the exception that the vessel used to hold the material was a wooden cylinder constructed for the purpose, instead of a box as in the former experiments. This cylinder consisted of white pine and was 8 inches long, 4 inches in diameter and with walls 1 inch thick. On one end was a wooden cover 1 inch thick which could be screwed on, and on the other was a very smooth copper plate tightly fastened on. The soil was poured in always from the side with the wooden cover and then compacted. The compacting was done by Bowman's compacting machine with few modifications. This whole apparatus is shown in Fig. 2. A is an arrangement especially made for the cylinder to rest on the copper cover and placed downward. The soil was poured in the top of the cylinder until the latter was full and then the crank was turned 20 times. The cylinder was filled more and the crank was turned again five times. The cylinder was then taken off the packing machine and all the edges were paraffined to make it air tight, and seven thermometers were placed along its axis at a distance of one inch apart and two inches deep. The cylinder was then placed on a stand as in the preceding experiment, and allowed to remain in the room several hours in order that the soil might acquire the room temperature, the latter remaining quite constant from day to day. The copper end of the cylinder was then brought in contact with the copper side of the source of heat. The temperature of the water in the bath was kept at about 33.5° C. as in the foregoing experiment, and the time required for the mercury column of the different thermometers to show a rise was noted. For simplicity as before, only the data for the thermometer 7 inches from the source of heat are represented below.

TABLE 9.—HEAT CONDUCTIVITY OF SOILS IN DRY STATE.

| Name of soil. | Minutes required for thermometer at 7″ to show rise in temperature. | Percent time required for thermometer at 7″ to show rise in temperature. |
|---|---|---|
| Sand | 38 | 100 |
| Gravel | 36.3 | 94 |
| Loam | 49.7 | 129.1 |
| Clay | 44.2 | 115.8 |
| Peat | 55.2 | 144.8 |

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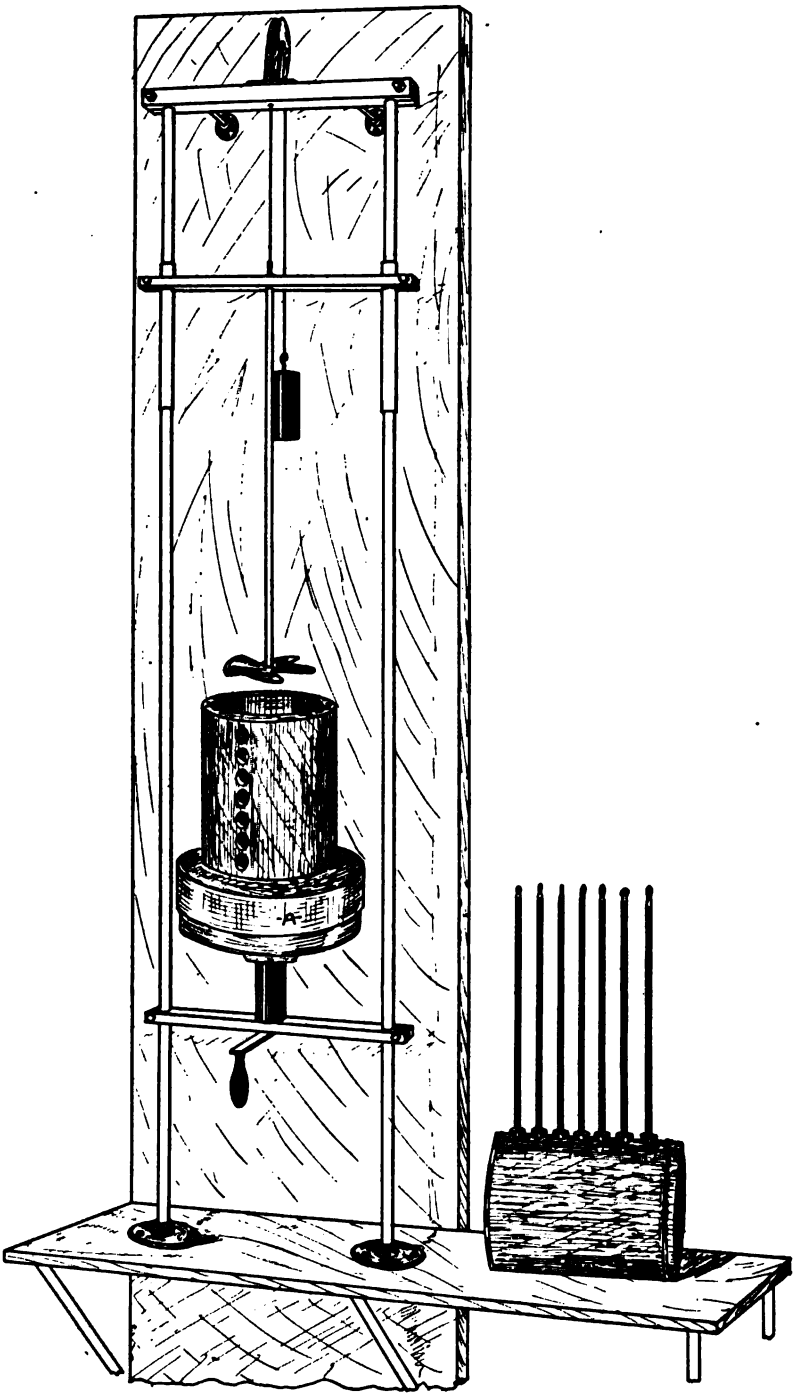

FIG. 2. SOIL PACKING APPARATUS AND CYLINDER CONTAINING THE SOIL.

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As in the case of the preceding experiments, this study shows that the gravel in the air dry condition conducts the heat the best and is followed by sand, clay, loam, and peat respectively.

A most interesting fact that was brought out very strikingly in this heat conductivity study of the different soils both in the air dry and moist state, was the difference in time in which the temperature of the column of soil began to rise at the different distances from the source of heat. The table below shows typical examples of this fact. The figures represent the time required for the heat to travel from one inch to another.

TABLE 10.—RATE OF RISE OF TEMPERATURE AT DIFFERENT DISTANCES FROM THE SOURCE OF HEAT.

| Name of soil. | 1 inch. | 2 inch. | 3 inch. | 4 inch. | 5 inch. | 6 inch. | 7 inch. |
|---|---|---|---|---|---|---|---|
| | Min. | Min. | Min. | Min. | Min. | Min. | Min. |
| Dry quartz sand | 2 | 7 | 6 | 12 | 7 | 3 | 3 |
| Moist loam | 1 | 5 | 10 | 10 | 9 | 7 | 2 |

It will be seen that the rate of flow of heat decreases until a certain distance is reached and then it increases.

A possible explanation for this phenomenon may be found in the rapid circulation of the soil atmosphere as eddy currents within the minute spaces between the soil grains. These eddy currents are probably set up as hot soil atmosphere on one side of a soil cavity which expands and moves up and is replaced by the colder gases. This circulation of air or convectional currents, undoubtedly greatly decrease the transfer resistance and as a consequence the heat conductivity values obtained do not represent the true and real heat conducting power of the material. To obtain this it is necessary to eliminate entirely these convectional currents. They can be eliminated to a very large extent by heating the soils from the top as, is done under field conditions by sun insolation, but the rate of diffusion would be increased in this case.

As a result of the part that these convectional currents play in heat conductivity, it is believed that the greater thermal transmitting power of the sand over the other soils is partly due to its capacity to allow a greater and more rapid circulation of air.

It will be interesting now to compare the heat conducting power of the different soils in these various conditions, both as to order and magnitude. Attention must be called here, however, to the fact that the magnitude of the results of the air dry soils cannot be compared with those of the moist natural soils because of the fact that the size of the vessels in the two cases was not the same, and consequently the volume of the materials was not the same. Therefore the comparison must be made among the different soils within the same experiment. Bearing this in mind, it will be found then (1) that the order of the thermal conductivity of the different types of soil in the air dry condition is exactly the same as that of the same soils measured in the natural state in the laboratory and under field conditions; and (2) that the differ-

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ences in magnitude among the different mineral soils in the air dry state is not very great, as is the case between these and the peat; while in the moist condition, the difference among the various mineral soils is also not highly large but there is a very great difference between them and the peat. This latter anomaly finds its explanation in the large difference in the water content of the two classes of soils. The variations are indeed very great, as shown in the table below which contains the moisture content of the different soils determined at various periods, also at the time when the soil cores were taken.

TABLE 11.—MOISTURE CONTENT OF THE DIFFERENT SOILS UNDER FIELD CONDITION AT DEPTH OF 7 INCHES.

| Date. | Gravel. | Sand. | Loam. | Clay. | Peat. |
|---|---|---|---|---|---|
| April 3 | 10.45 | 11.96 | 40.70 | 29.16 | 256.70 |
| July 27 | 6.156 | 3.60 | 36.64 | 25.80 | 148.60 |
| September 9 | 10.41 | 5.07 | 41.40 | 31.95 | 159.10 |
| November 4 | 6.91 | 3.78 | 38.12 | 26.81 | 135.50 |
| October 20 | 7.5 | 4.24 | 39.52 | 27.60 | 234.00 |

These figures show that the peat usually contains about 25 times as much water as sand or gravel do and about 5 times and 4 times as much water as clay and loam respectively. Now it has been demonstrated that water exerts a tremendous influence upon the thermal conductivity of soil materials both on account of its high specific heat and because of its influence on the structure of the soil. It has been shown also that water is a poorer conductor of heat than the soil material in the ratio of 1:7 when the latter is compacted into a rock; yet water is by far a better thermal transmitter than air. In a well moistened state a soil may transmit heat many times as fast as in the air dry state. In the dry state the soil grains are surrounded by air which acts as an insulation to the passage of heat, consequently the heat transmission is retarded. In the well-moistened condition, however, the air is replaced by the water and the soil grains are enclosed by the water films. These water films perform two functions (1) they replace or expel the air as already stated, and (2) they reduce the pore space and thereby bring the soil particles in more intimate contact or in a more continuous massive condition. It is by producing these effects that water increases so greatly the thermal conductivity of soils so that its own opposing effect, on account of its poorer power of heat transmission, is offset or overshadowed. If water, however, is present in a soil above a certain amount which amount varies with the different soils due to their different water holding capacities, the temperature of this soil will rise more slowly because of the very large heat capacity of water, which is almost five times that of the soil, yet heat will travel faster thru the soil in the more saturated condition than in the moist state. It is on account of the greater water content and hence of the larger specific heat that the peat shows poorer heat transmitting power than the mineral soils in their natural state as compared in their air dry condition. It is an interesting coincidence that the mineral soils and especially the sandy soils have both a better thermal conducting power and a smaller water holding capacity than the peat. These factors

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seemingly tend to exaggerate the thermal relations of these series of soils very greatly.

### DIRECTION OF SOLAR HEAT IN FIELD SOILS.

It will be interesting to consider at this time the direction in which the solar radiation travels thru the soil and the part that the moisture plays in this progression. At first thought it would seem that the surface heat will travel thru the soil equally in all directions, vertically as well as horizontally. Such, however, may not be the case if the surface varies in color or in other respects, as the following experiments seem to indicate. This point was studied in the following manner: On a very level and smoothed surface ground was spread quartz sand dyed black and very white quartz sand. On the line where the two sands came together, as well as on each side of this line, were placed at various distances, thermometers at the same and at different depths. The temperatures of this ground so treated were read on the thermometers on clear and sunny days. The results obtained are shown herewith:

TABLE 12.—MOVEMENT OF SOLAR HEAT IN SOILS UNDER FIELD CONDITIONS.

| | | |
|---|---|---|
| Central line sharp, ie., black and white | 84.4°F | 3″ deep. |
| 1″ from central line towards **black** | 84.4 | 3″ deep. |
| 1″ from central line towards white | 83.6 | 3″ deep. |
| 2″ from central line towards **black** | 85.0 | 3″ deep. |
| 2″ from central line towards white | 83.4 | 3″ deep. |
| 4″ from central line towards **black** | 85. | 3″ deep. |
| 4″ from central line towards white | 82.8 | 3″ deep. |
| 8″ from central line towards **black** | 86.2 | 3″ deep. |
| 8″ from central line towards white | 82.4 | 3″ deep. |
| 8″ from central line towards **black** | 84.0 | 4″ deep. |
| 8″ from central line towards white | 80.5 | 4″ deep. |
| 2″ from central line towards **black** | 83.8 | 4″ deep. |
| 2″ from central line towards white | 82.4 | 4″ deep. |
| 8″ from central line towards **black** | 82.7 | 5″ deep. |
| 8″ from central line towards white | 80.0 | 5″ deep. |
| 1″ from central line towards **black** | 81.5 | 5″ deep. |
| 1″ from central line towards white | 81.0 | 5″ deep. |

The data show (1) that the temperature of that side of the line having the white sand is much lower than that of the side with the black sand, but that the temperature of the former is much higher near the neutral line than farther away; (2) that a marked difference in temperature may exist within a distance of an inch; and (3) that the temperature of the black sand covered soil is higher at the 4-inch depth than the white sand covered soil at the 3-inch depth when the measurements in both cases are taken at two inches from the central line. At 8 inches from the neutral line the black covered soil at the depth of 5 inches has also a slightly higher temperature than the white covered soil at the depth of only 3 inches.

These results, therefore, seem to indicate very strongly that while the soil temperature tends to travel vertically as well as horizontally, the amount or the facility with which it goes in the former direction is greater than in the latter path. Theoretically that is what should be expected since heat tends to travel at a greater rate in the presence of larger amounts of moisture and since the moisture content of the soil tends to increase with the depth.

The important question to consider next is what part heat conduc-

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tivity plays in the control of temperature of the different soils under natural field conditions. This is indeed a very difficult question to answer definitely and satisfactorily for the reason that these soils have different water holding capacities, consequently the great influence that this inequality of water content has upon the travel as well as upon the rise and fall of temperature.

It is commonly believed, however, that heat conductivity has a very important and beneficial influence because the soils with the greater heat conducting power are generally warmer both at the upper surface and at lower depths due to the fact that the heat travels to greater depths during the sun insolation and during the night or cold periods, this heat returns to the surface and thus keeps it warmer. In the case of soils of poor thermal transmitting power only their upper surface will be heated during the sun insolation and during the night this heat will be radiated into space and the soils are left cooler.

Theoretically this argument is sound, but in nature, as shown by the results of the different types of soil, later to be presented, it does not seem to be borne out. It will be found that in the summer, fall, and winter months, the average temperature of all the different types of soil is about the same with a small difference in favor of the loam, clay, and peat respectively. In the spring months, however, the temperature of the sand and gravel began to rise sooner than that of the latter soils. This, however, may be attributed largely to the different amount of heat that is required to warm a cubic foot of the various types of soil to the same degree on account of their different water content. The sameness in temperature of these soils in the fall is also largely due to their different moisture content or specific heats as will be explained.

Everything considered it does not appear that heat conductivity alone plays a very important part in the warming and cooling of the soils in the spring and fall respectively, which seasons from the agricultural or practical standpoint are the most important. The force of this statement will be evident when we come to consider the results of the field experiments. Even the heat conductivity between cultivated and uncultivated soil does not appear to be of such a great practical importance. The difference in temperature that is observed in these differently managed soils is mostly due to the dry mulch at the surface of the cultivated soil.

Where heat conductivity may be of great importance and of practical benefit is in the spring daylight hourly march of soil temperature. If the temperature of a sandy soil at a depth of 6 inches begins to rise two or three hours earlier every day than that of a clay soil, the plants grown in the former soil will have that number of hours of more favorable daylight growth, at which time the carbon assimilation and other activities are at their maximum.

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## EFFECT OF COLOR ON RADIATION AND THE RADIATING POWER OF SOILS UNDER DIFFERENT CONDITIONS OR TREATMENTS.

### OBJECT AND METHOD OF EXPERIMENTATION.

Radiation has already been defined as a process in which heat is propagated as a free-wave motion without permanently affecting the intervening space between the radiating body and the body receiving the radiant energy. The phenomenon is likened to light. Like the latter it is propagated in straight lines; it is reflected and refracted; it travels with great rapidity; and obeys the same laws of propagation.

Our knowledge concerning the rate of radiation or of cooling of substances is unsatisfactory. Newton seems to be the first who performed experiments on the subject. From the data he obtained he enunciated the law to the effect that the quantity of heat lost or gained by a body in a second is proportional to the difference between its temperature and that of the surrounding medium. Dulong and Petit, however, proved that this law is not general but applies only with differences of temperature which do not exceed 15° to 20°. Beyond this, the quantity of heat lost or gained is greater than what is required by this law.

In 1879 Stefan showed, from his own researches and from recalculating his predecessors' data upon the subject, that the rate of radiation of a body is proportional to the fourth power of its absolute temperature.

On account of the great complexity of the phenomenon and of the insurmountable difficulties involved in the technic, the radiating power of only a few substances has been determined. This limited study, however, has conclusively revealed that the different materials have different radiating or emissive capacity. This is also true of the same substance in different conditions and in different temperatures.

In the investigation here presented the main object has been to discover the radiating power of different soils under various conditions or treatments and thereby see, if possible, to what extent radiation affects the temperature of soils. As will be stated later, this subject has remained practically unexplored. Indeed, there has been only one man who has attempted to investigate it.

The different soils experimented with were quartz sand, gravel, loam, clay and peat,—the true representatives of the most common soils.

These soils possess, among other characteristics, distinctive differences in color. It is a common opinion that color has a very marked effect upon the radiation as well as upon the absorption of heat. It is claimed that radiation and absorption are closely related, that the highest absorbers are also the highest radiators and the lowest absorbers are the lowest radiators. A black substance for instance being able to absorb practically all the heat rays on account of its low reflection, low diffusive and high absorptive power, is a high heat absorber and consequently a high heat radiator. The opposite is true of a white substance. A white substance on account of its high reflective, high diffusive and low absorbing power, is a low absorber and, therefore, a low radiator.

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It is concluded by some soil physicists, therefore, that a black soil attains a very high temperature during the sun insolation but in the early morning its warmth is about the same if not lower than that of a light colored soil.

A number of physicists have investigated the effect of color on radiation but, as far as the writer is aware, only two have studied it in its application to soil temperature. The first worker was Lang.[12] His method of study consisted of determining the radiation of a white substance first and then mixing this with a colored substance, such as soot, and determining again the radiation of the mixture. He concluded from his results that color affects radiation and absorption equally well.

Several years later [13]Ahr reinvestigated the subject. He employed a slightly different arrangement in the apparatus but used practically the identical material of Lang. He obtained results which were practically the same as his predecessors' but he did not deduct the same conclusions. He thought that the difference in radiation observed in the various colored substances might be due to the composition of the material rather than to the color.

Since this question was still unanswered, and since it was desirable to know definitely whether color does affect radiation in order to arrive at proper conclusions on the radiating power of the different types of soil already mentioned, it was deemed necessary and advisable to investigate the subject. Such investigation, it appeared, should be conducted differently from that of the previous investigators if more definite and conclusive results were to be obtained. One of the greatest difficulties that this study presents, is the fact that there is no single substance of the same composition which contains all the different rays of the spectrum. It seemed, however, that this difficulty might be overcome, to some extent at least, by the following procedure: Instead of using different solid materials of entirely unlike composition to obtain the different colors, it was thought best to use the same kind of solid material colored with the different aniline dyes. The solid substance employed was quartz sand and its radiation as affected by color was measured by an apparatus to be described.

The instruments commonly employed in studying or measuring radiation are the thermopile and bolometer. The bolometer is the more sensitive instrument of the two. On account of various reasons, however, it could not be obtained; consequently at the beginning of the work a high grade thermopile with a very sensitive galvanometer were employed.

The results obtained by this method were unsatisfactory because of the fact that one end of the thermopile was exposed to the room temperature, a slight change in which would change the readings. In order to overcome this difficulty a thermopile was constructed one end of which could be kept in ice water and thus kept under a better controlled temperature. This change or improvement, however, proved of no avail as the electomotive force was so great on account of the large difference in temperature between the two ends that the deflection on the unshunted galvanometer would invariably go beyond the scale.

(12) Forsch. a. d. G. d. Agrik. Phy. 1. 1878.
(13) Forsch. a. d. G. d. Agrik. Phy. XVII, 1894.

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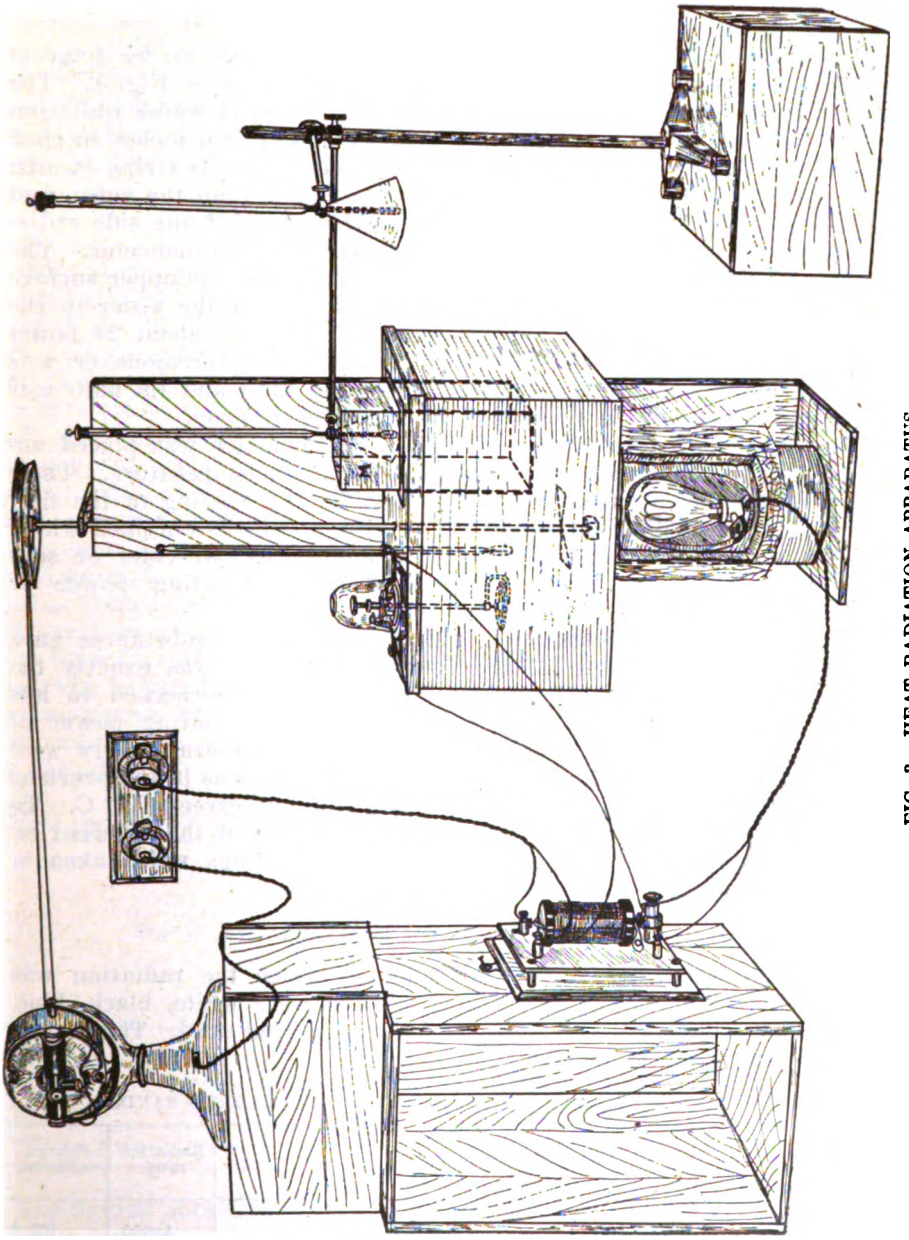

FIG. 3. HEAT RADIATION APPARATUS.

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On account of these obstacles, also because of the fact that the accuracy of the thermopile is considerably reduced by the many accidental electrical currents, the thermopile, as a radiometer, was finally abandoned in favor of a Beckmann thermometer. This thermometer gave very satisfactory results.

The complete apparatus employed for the study is shown by diagram 3. With the exception of part M, it is the same as in Fig. I. The part or vessel M is a box in which was placed the sand whose radiation was to be studied. It is made all of copper and it is 6 inches in each dimension. Inside of all four sides were placed asbestos strips ⅛-inch thick and about 10 inches high, or 4 inches higher than the sides, and extending to the bottom—they were intended to prevent any side radiation from the copper vessel or other sources to the thermometer. The box was filled with the sand to a certain height so that the upper surface of the sand would be even with the upper surface of the water in the constant temperature bath, and was left in the latter about 24 hours in order to acquire the constant temperature. The thermometer was placed about one inch from the surface of the sand and its bulb was protected from any side radiations by the cone or hood.

Near the radiation receiving Beckmann thermometer was placed another Beckmann thermometer to indicate the room temperature. Their readings were taken simultaneously and when the reading of the first thermometer is divided by that of the second, a ratio is obtained which is designated as the radiating power of any particular color or soil. Throughout this investigation, then, the relative radiating power of different materials is reduced to this ratio.

This method of measuring the radiating power of substances gave most satisfactory results. If the room temperature was exactly the same the readings of duplicate experiments could be checked to less then 1%. In the measurement or study of the radiating power of any color or soil, therefore, the readings of the two thermometers were taken when the room temperature was about the same as in the previous or standard experiment and the variation did not exceed 0.2° C. To eliminate also any errors that may arise on account of the different reflective powers of the various materials, the readings were taken in every case in dark.

### EFFECT OF COLOR ON RADIATION.

There were six different colored sands in which the radiation was measured by the foregoing method. These were white, black, blue, green, red and yellow. The white was the uncolored sand. The results obtained are given herewith:

TABLE 13.—THE RADIATION OF DIFFERENT COLORED SANDS.

| Name of colored sands. | Radiation ratio. | Percent radiation. |
|---|---|---|
| White | 1.060 | 100.0 |
| Black | 1.051 | 99.15 |
| Blue | 1.045 | 98.10 |
| Green | 1.040 | 98.12 |
| Red | 1.050 | 99.06 |
| Yellow | 1.048 | 98.87 |

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The first column of figures from the left represent the relative radiation ratio. The last column contains the same data reduced to the percentage basis with the white sand as 100% or unit. A glance at these figures reveals at once the fact that the radiating power of the different colored sands is the same, the greatest range being between the white and green sands which is only 1.88% and which is quite within the experimental error.

From these data we are justified in concluding that color has no effect on radiation, at least at this low temperature. It does have on absorption, however, as will be shown below.

### EFFECT OF COLOR ON ABSORPTION OF HEAT.

This study was conducted by filling wooden boxes 12 inches square, 2 inches high with bottom and no top, with the various colored sands employed in the preceding investigation, placing them outdoors during *hot* and clear days and recording the temperature at various intervals for 24 or more hours, with mercury thermometers graduated to 0.1° C. There were several experiments conducted but for the sake of brevity only two are given here. The first was conducted on July 27 when the sky was perfectly clear from early morning till about 6 in the afternoon. From this hour on the sky was clouded and about five o'clock the next morning it began to rain. The temperature records were taken every hour during all this time. The second experiment was performed on August 5. This day was also hot and the sky perfectly clear from clouds from morning till evening and even on the succeeding day. The temperature was recorded every hour till the maximum was attained and then at various intervals till late at night, again at 4:30 the next morning before the sun appeared. In the table below, however, only the maximum and minimum readings of both experiments are given. The minimum readings were taken in order to obtain further light on the effect of color on radiation.

TABLE 14.—EFFECT OF COLOR ON THE RISING AND LOWERING OF TEMPERATURE.

| Name of colored sand. | July 27–28. | | August 5–6. | |
|---|---|---|---|---|
| | Max. | Min. | Max. | Min. |
| | 2:00 p. m. | 4:00 a. m. | 1:30 p. m. | 4:30 a. m. |
| Black | 40.9 °C | 16.7 °C | 37.6 °C | 12.45°C |
| Blue | 40.0 | 16.65 | 36.7 | 12.4 |
| Red | 38.55 | 16.65 | 35.9 | 12.4 |
| Green | 37.10 | 16.60 | 34.7 | 12.3 |
| Yellow | 35.8 | 16.60 | 32.65 | 12.25 |
| White | 34.6 | 16.44 | 31.7 | 12.2 |

The figures obtained at both times show that the various colors have a most significant different absorptive power for the rays of the sun. The black absorbed the greatest amount and hence attained the highest temperature, followed in order by blue, red, green, yellow and white,

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respectively. The difference between the black and white on July 27 was 6.3° C. and on August 5.6° C. The differences between the other colors are not so great, especially between the black and the blue, the yellow and the white, the red and the green.

The minimum figures, on the other hand, show very conclusively at both times that the temperature of all the different colored sands is practically the same, the difference in any extreme not being more than .3° C. and in favor of the sands which had attained the highest temperature. These results are interesting because they lend further confirmation to the conclusions already announced that color has no effect upon radiation. This conclusion, however, may be objected to because if the different colored sands attained different temperatures during the sun insolation because of their different absorptive powers, while during the night they all cooled to the same point, then they radiated differently, and therefore those colors which caused the highest absorption lost the most heat. This is all true but those sands which lost the most heat did not do so on account of the greater radiation of their color, but rather because of the difference between their temperature and that of the air. The law of cooling as announced by Newton states that the rate of cooling of a body is proportional to the difference in temperature between its own and that of the surrounding medium, while the similar law of Stefan states that the rate of cooling or radiation of a body is proportional to the fourth power of its absolute temperature.

Theoretically speaking color should have no effect upon radiation because all colors emit in dark, rays of low refrangibility which are the same while the rays they absorb from the sun are of high refrangibility and are different. The different radiating power observed in the different colored substances is probably due, therefore, to the difference in their composition rather than to their color.

### RADIATING POWER OF NATURAL SOILS.

The radiating power of different soils was studied under three different conditions or treatments: (1) in dry and powder state; (2) with moist subsurface and dry surface; and (3) in the natural condition. For convenience these headings will be considered in reverse order.

As has already been stated the radiating power of soils has been studied thus far only by Ahr.[14] He conducted experiments on the radiating capacity of different kinds of soils in the dry, moist, and wet condition. In the dry condition he obtained the following results: quartz 96.5, loam 94.4, calcareous sand 94.1, kaolin 91.5, and humus 89.8%. In the moist and wet condition the values were higher but were the same for all the soils.

In the investigation of heat conductivity, natural cores of soils were employed. These same cores of the different types of soil were also used in the study of radiation with the object of arriving at more definite and practical conclusions as to their radiating power.

The study was conducted by taking off both covers of the box containing the core, pushing the latter very gently with a block of board

(14) Forsch. a. d. G. d. Agrik. Phy. XVII, 1894.

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of the same size as the inner side of the box, until it was about 1 inch from the top of the box. That portion of the core which extended beyond the edge of the other end of the box was cut off carefully with a sharp knife. The box containing the core was then placed in a metallic vessel with bottom and no top and made especially to fit this box. That side of the core which rested on the bottom of the vessel, was the subsoil, while that side which was exposed and came to one inch from the top of the box was the surface soil. The latter side was then covered with a very thin sheet of mica in order to prevent evaporation which would have affected the radiation. This mica being diathermous permitted the passage of the radiant energy. The sheet was of the same dimensions as the box so that it rested upon its edges and was about one inch above the surface soil. Its ends were fastened to the edges of the box by means of paraffin, thus making the box air tight. An extension box 5 inches high and 8 inches in diameter was placed on the top of this other box and was also fastened on by paraffin. The ends of the mica came then between the edges of the two boxes. The second or extension box was placed there in order to prevent side radiations on the bulb of the thermometer when it was brought one inch from the surface of the mica to receive the radiation of the soil. The metalic vessel containing the prepared soil box was then placed into the constant temperature bath, the temperature of which always remained at about 33° C. and not varying more than 0.2° C. On the top of this vessel were bended horizontal edges by means of which it was hung from the top or cover of the water tank. In this manner the surface of the soil was always below the surface of the water in the tank. The soil was left in the bath about 24 hours in order to acquire the constant temperature and the radiation readings were taken in the same manner as in the preceding experiment. The radiating power of the cores of all the different soils was studied, then, in this manner and the results obtained are given in the following table:

TABLE 15.—RADIATING POWER OF THE CORES OF THE DIFFERENT SOILS.

| Name of soil. | Radiation ratio. | Percent radiation. | Percent moisture. |
|---|---|---|---|
| Sand | 1.697 | 100.00 | 4.24 |
| Loam | 1.694 | 99.82 | 39.20 |
| Clay | 1.682 | 99.01 | 27.6 |
| Peat | 1.690 | 99.59 | 234.00 |
| Water | 1.946 | 114.70 | ..... |

It is at once seen that all the different types of soil in their natural and well-moistened condition possess exactly the same radiating power. Water, however, has a different and much higher radiating capacity. Evidently these results agree with those of Ahr's.

### RADIATION OF SOILS WITH MOIST SUBSURFACE AND DRY SURFACE.

During the warm part of the year the soils have a dry surface and a moist subsurface. In order to ascertain what effect this condition



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would have upon their radiating capacity the study presented below was undertaken.

It is unfortunate that natural soils could not also be used for this investigation. The study, therefore, had to be conducted with artificial soils in the following manner: The soil was finely ground, moistened, put into the same vessel as that which contained the core of soil, well compacted, covered with the sheet of mica and the extension box put on. The radiation readings were then taken as in the previous case. Then about an inch of the moist soil was removed and replaced by the same kind of soil in a dry and powered form. The box was prepared as usual and the radiation taken again. The difference, if any, between the first and second readings would show whether dry surface with moist subsurface affected the radiation in any way differently from the moist surface and subsurface. The data obtained in this study are given in the table below:

TABLE 16.—RADIATION OF SOILS WITH DRY SURFACE AND MOIST SUBSURFACE.

| Name of soil. | Radiation ratio. Moist surface. | Radiation ratio. Dry surface. | Per cent radiation. Moist surface. | Percent radiation. Dry surface. | Percent moisture. |
|---|---|---|---|---|---|
| Gravel | 1.668 | 1.542 | 100 | 92.44 | 4.76 |
| Sand | 1.668 | 1.553 | 100 | 93.10 | 5.32 |
| Loam | 1.678 | 1.524 | 100 | 90.89 | 25.85 |
| Clay | 1.670 | 1.530 | 100 | 91.06 | 17.25 |
| Peat | 1.502 | 1.293 | 100 | 86.09 | 84.94 |
| Water | 1.946 | | | | |

This table shows very conclusively that all the different soils with a dry surface radiate less than with a moist surface. In other words a dry surface greatly reduces the amount of radiation. It will be seen that all the mineral soils radiated from 7 to 9% and the peat 15% less when they are covered with a dry thin layer of soil than when all the mass is moist. It is interesting to observe that all the mineral soils radiated about the same when moistened through which confirms the results of the preceding experiment—and that their radiation is cut down to about the same amount by their respective dry mulches. The peat, however, shows somewhat a lower radiation. Another noteworthy fact is the insignificant difference in radiation between any of the mineral soils when they are almost saturated and when medium moist. By comparing the first column of the above table with the corresponding one in table 15, it is at once seen that the difference does not amount to more than 1%. In the case of peat, however, the difference runs as high as 11%.

### RADIATION OF SOILS IN DRY STATE.

Mention has already been made that the radiating power of the different types of soil was determined also in their air dry state. This study has, of course, more theoretical than practical value but it was undertaken with a three-fold purpose in view: It was desired to ascertain (1) the relative radiating power of these soils in their dry condi-

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tion; (2) to see how this compared with their radiating power in their moist state; and (3) to compare their radiating power with their heat transmitting power, in their air dry condition. The investigation was conducted in the same manner as the preceding one with the exception that in the present case all the soils were dry and their particles were of about the same size, i. e., they passed a 40 mesh sieve. This latter precaution was taken because preliminary experiments showed that radiation tends to increase slightly with the increase in size of particles. The results obtained are given in the following table:

TABLE 17.—RADIATION OF THE DIFFERENT SOILS IN THEIR DRY CONDITION.

| Name of soil. | Radiation ratio. | Percent radiation. |
|---|---|---|
| Sand | 1.472 | 100.00 |
| Gravel | 1.375 | 93.4 |
| Loam | 1.369 | 93.0 |
| Clay | 1.391 | 94.45 |
| Peat | 1.194 | 81.12 |
| Water | 1.946 | 132.2 |

This table shows that the radiating power of the different soils in the dry condition is different, that the sand shows the highest radiation, followed in order by the gravel, clay, loam and peat, respectively and that the difference between the first and last soil is very marked. This latter fact is highly important because it lends further evidence to the theory that radiation is independent of color. The table also shows that water exhibits the greatest radiating power. This would point to the conclusion that it is the water which increases so markedly the radiating power of moist soils, and which overshadows their radiation possessed in their dry state. This greater radiating capacity of water is contrary to the common belief. The widely held opinion is that water radiates its heat with greater difficulty than any soil material. The truth of the matter is, however, that water loses its heat slowly, not because of its low radiating power but because of its high heat capacity.

It has been stated that the radiating power of these different soils in their dry condition was investigated partly in order to compare it with their heat conducting power. The results show that the two properties run together, a fact contrary to the statements of some physicists.

It now remains to consider the practical significance of the foregoing results. The studies on the specific heat (of dry soils) and heat transference in natural soils led to the conclusion that these two properties play a small part in determining the temperature of the different soils, especially during the important seasons of the year. Radiation plays still a smaller part. This inference is inevitable in the light of what has already been obtained. It has been conclusively shown that all the different types of soil when well moistened possess exactly the same radiating power, and when they have a thin layer of dry mulch this power varies only slightly. This means then that all these soils, under field conditions, cool at the same rate as far as their property of radiation is concerned, the different rate of cooling and warming that is actually observed among these soils is, therefore, due mostly to their different moisture contents and hence to their different specific heats.

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## TEMPERATURE OF DIFFERENT TYPES OF SOIL.

### OBJECT AND METHOD OF EXPERIMENTATION.

This phase of the project had for its primary purpose the investigation of the temperature, under field conditions, of the most common and representative types of soil, namely, gravel, sand, loam, clay and peat. These soils possess so many distinct differences in their physical and chemical properties that it was desired to ascertain whether their temperature relationships would also be different. The mechanical analysis, as determined by the centrifuge method, and the percentage of organic matter, as determined by the loss on ignition method, of these soils, are shown in the following table:

TABLE 18a.—MECHANICAL ANALYSIS AND PERCENTAGE OF ORGANIC MATTER OF THE DIFFERENT TYPES OF SOIL.

| Soils. | Stones. | Fine gravel. 2. — 1. | Coarse sand 1. — .5. | Medium sand .5 — .25. | Fine sand .25 — .10. | Very fine sand .10 — 2.5. | Silt 05 — .005. | Clay 0.005. | Per cent. organic matter. |
|---|---|---|---|---|---|---|---|---|---|
| Gravel | 32 | 9.70 | 20 20 | 51.90 | 7.10 | 1.34 | 5.47 | 4.29 | 4.08 |
| Sand | | 1.42 | 13.25 | 67.85 | 13.10 | 1.65 | 1.02 | 1.71 | 2.45 |
| Loam | | 1.66 | 2.70 | 13.82 | 11.66 | 8.70 | 47.24 | 14.22 | 12.41 |
| Clay | | | | 1.78 | 1.72 | 3.69 | 61.13 | 31.68 | 7.97 |
| Peat | | | | | | | | | 71.61 |

Our knowledge concerning the temperature of these different types of soil is very meager. Only two investigators appear to have studied the subject: [15]Wollny and [16]Ebermayer. Wollny made observations of the temperature of sand, clay, and peat for long time. He noticed that sand heats and cools with the greatest rapidity followed by clay and peat and that their average temperature of long period differs but slightly. Ebermayer studied the temperature of sand, clay, loam and peat. From the data he obtained he arrived at practically the same conclusions as Wollny.

The present investigation was conducted in the following manner: A long trench was dug on a smooth and slightly rolling piece of ground a little over 3 feet deep and 3 feet wide. A layer of sandy soil about 6 inches deep was spread over the bottom of this trench so that there would be a uniform bottom. Into this trench, about one foot apart, were placed five wooden boxes 3 x 3 x 3 feet without bottom or top. These boxes were first filled with the above different types of soil about the latter part of September, 1911, were flooded several times in order to compact, and finally were covered with a very thin layer of the same kind of soil in order to eliminate the factor of color. The effect of this factor was investigated in a separate experiment. Their temperature recording was preliminarily begun in the middle of November, but was

(15) Forsch. a. d. G. d. Agrik. Phy. XIX: 305, 1896.
(16) Forsch. a. d. G. d. Agrik. Phy. XIV: 399, 1891.

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really commenced on December 1. The temperatures were taken daily except Sundays throughout the year by means of electrical resistance thermometers at three different depths, 6, 12 and 18 inches, at 7 a. m., 12 m., and 6 p. m. The electrical resistance thermometers were obtained from Leeds and Northrup, Philadelphia, Pa., and consisted of the resistance bulb and 35 ft. wire leads. The latter were incased in lead pipes so as to keep them dry and well insulated. The ends of these leads were run into a house especially constructed for the purpose. In this house also was kept on a permanent stand, a balance indicator upon which the temperatures were indicated.

This electrical temperature measuring apparatus gave satisfactory results. If the indicator was in good working order the readings could be relied upon to be accurate to within 0.2° to 0.5° F. The accuracy and sensitiveness was not as high as it was desired, but this lack was somewhat compensated or overcome by taking three readings daily and averaging them. Furthermore, when it is considered that the high and low temperatures recorded during the day do not represent the real maximum and minimum temperatures, then the accuracy of the apparatus is sufficiently high.

As already stated the soil temperature obtained under field conditions is the resultant of many factors. These factors may be divided into two general groups, intrinsic and external. The intrinsic factors comprise specific heat, heat conductivity, thermal absorption and radiation, specific gravity, texture and structure, topographic position, concentration of the soil solution, moisture content, etc. The external includes the meteorological elements, chief of which are air temperature, sunshine, wind velocity, barometric pressure, precipitation, dew point, humidity, etc. The intrinsic factors vary with the different soils and control their temperature for any particular day or season. They are acted upon by the external factors which cause the soil temperature to vary from day to day as they themselves vary. Variations in temperature, therefore, in the different types of soil for any particular period will depend upon their different intrinsic factors, but the variations of all these soils for succeeding days will depend upon the external factors. These meteorological elements influence the soil temperature either directly or indirectly. Pressure, for instance, exerts an indirect effect by either depressing or accelerating evaporation. The amount of evaporation is least when the barometric pressure is high and greatest when it is low.

In connection with the study of the soil temperature of the foregoing soils, these external meteorological factors or elements have also been studied. With the exception of the air temperature which was recorded by an air thermograph located near the soil plots, all the other atmospheric elements were recorded by the proper instruments at the Weather Bureau[17] office which is situated only a very short distance from the experiment.

The following tables show the daily and monthly average, maximum and minimum, also the seasonal and yearly average, maximum and minimum, temperature of the five different types of soil. Each table is accompanied by a diagram to show in a graphic representation its salient

(17) The writer wishes to express his gratitude to Mr. D. E. Seeley for permission to consult and use these weather records.

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facts, also the daily march of the meteorological elements and their influence upon the soil temperature.

## DAILY AND MONTHLY AVERAGE TEMPERATURE.

TABLE 18.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, DECEMBER, 1911.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 31.8 | 33.33 | 36.36 | 31.83 | 33.83 | 37.06 | 31.96 | 34.5 | 37.16 | 31.96 | 34.53 | 36.53 | 31.93 | 34.33 | 37.36 |
| 2 | 31.6 | 33.23 | 36.43 | 31.4 | 33.6 | 36.86 | 31.83 | 34.5 | 37.56 | 31.73 | 34.73 | 36.4 | 32. | 34.3 | 37.63 |
| 4 | 31.6 | 33.33 | 36.46 | 32. | 34.13 | 36.56 | 32.06 | 36.96 | 36.96 | 32.1 | 34.63 | 36.8 | 31.96 | 34.33 | 37.43 |
| 5 | 32.43 | 34.23 | 36.33 | 31.9 | 33.93 | 36.8 | 32.06 | 36.96 | 36.93 | 32.46 | 34.9 | 36.73 | 32.43 | 34.33 | 37.3 |
| 6 | 32.26 | 33.8 | 36.33 | 31.96 | 33.9 | 36.63 | 32.4 | 34.43 | 36.93 | 32.33 | 34.43 | 36.43 | 32.06 | 34.3 | 37.06 |
| 7 | 31.6 | 33.33 | 35.86 | 31.46 | 33.43 | 36.1 | 31.8 | 33.96 | 36.53 | 32. | 33.93 | 36. | 31.8 | 33.86 | 36.96 |
| 8 | 32.26 | 33.93 | 36.1 | 32.73 | 34.1 | 36.63 | 32.46 | 34.76 | 37.03 | 32.76 | 34.73 | 36.26 | 32.26 | 34.5 | 37.06 |
| 9 | 38.26 | 37.73 | 37.53 | 39.43 | 38.06 | 37.73 | 33.46 | 35.1 | 37.3 | 35.38 | 36.06 | 36.96 | 32.53 | 34.43 | 37. |
| 11 | 41.83 | 42.06 | 41.6 | 41.2 | 41.7 | 40.96 | 40.73 | 39.96 | 39.03 | 41.63 | 40.6 | 39.9 | 32.26 | 33.9 | 36.96 |
| 12 | 38.13 | 40.2 | 41.2 | 37.33 | 39.13 | 41.06 | 38.96 | 40.16 | 40.4 | 39.3 | 40.7 | 41. | 32.5 | 34.63 | 37.46 |
| 13 | 36.83 | 37.83 | 39.86 | 35.43 | 37.46 | 39.86 | 36.8 | 39.1 | 40.33 | 36.76 | 39.23 | 40.33 | 32.73 | 35.2 | 38.13 |
| 14 | 33.96 | 35.53 | 38.23 | 33.23 | 35.36 | 38.16 | 34.6 | 37.33 | 38.76 | 33.86 | 36.23 | 38.6 | 32.46 | 34.86 | 38.1 |
| 15 | 33.33 | 35.2 | 37.83 | 33.16 | 34.2 | 37.86 | 34.1 | 36.76 | 38.9 | 34. | 36.53 | 38.23 | 32.53 | 34.8 | 37.86 |
| 16 | 33.8 | 35.46 | 37.76 | 33.76 | 35.3 | 38.06 | 33.93 | 36.7 | 38.96 | 34. | 36.66 | 38.13 | 33.23 | 35.56 | 38.9 |
| 18 | 33.93 | 35.46 | 37.8 | 33.93 | 35.7 | 37.96 | 33.8 | 36.06 | 38.16 | 34.13 | 36.16 | 37.86 | 33.23 | 35.86 | 38.2 |
| 19 | 34.96 | 36.06 | 38. | 34.66 | 36.13 | 38.33 | 34.5 | 36.6 | 38.93 | 34.8 | 36.8 | 38.1 | 34.1 | 36.2 | 38.93 |
| 20 | 33.9 | 35.76 | 37.2 | 33.66 | 35.13 | 37.36 | 33.36 | 35.83 | 38. | 33.73 | 36.2 | 37.83 | 33.33 | 35.36 | 38.26 |
| 21 | 32.96 | 34.3 | 36.5 | 32.6 | 34.26 | 36.73 | 32.5 | 34.93 | 37.26 | 32.6 | 35.1 | 36.46 | 32.2 | 34.43 | 37.13 |
| 22 | 32.96 | 33.56 | 35.63 | 33.2 | 34.06 | 35.86 | 32.06 | 33.96 | 36.2 | 32.8 | 34.46 | 35.8 | 31.8 | 33.63 | 36.5 |
| 23 | 33.45 | 34.7 | 36.4 | 32.75 | 34.5 | 36.45 | 32.5 | 34.5 | 36.1 | 33.15 | 34.75 | 35.85 | 31.65 | 33.4 | 36.35 |
| 25 | 32.5 | 34. | 35.9 | 32. | 33.9 | 35.8 | 32.1 | 34.2 | 36.4 | 32.2 | 34. | 35.9 | 31.9 | 33.5 | 36. |
| 26 | 32.23 | 33.33 | 35.66 | 31.66 | 33.5 | 36.13 | 31.56 | 34.03 | 35.96 | 32.13 | 33.96 | 35.76 | 31.76 | 33.33 | 36.06 |
| 27 | 31.76 | 33.56 | 34.9 | 32.76 | 33.73 | 35.5 | 31.73 | 33.73 | 36.13 | 32.46 | 33.53 | 34.9 | 32.26 | 33.53 | 35.13 |
| 28 | 31.93 | 32.73 | 39.16 | 31.23 | 33.13 | 35.93 | 32.46 | 34.3 | 36.73 | 32.7 | 34.73 | 35.4 | 32.13 | 34.06 | 36.1 |
| 29 | 30.5 | 31.76 | 34.2 | 29.96 | 32.26 | 35.4 | 30.93 | 33.36 | 35.73 | 30.93 | 33.4 | 35. | 31.83 | 33.4 | 36.23 |
| 30 | 30.26 | 31.13 | 33.43 | 30.26 | 31.4 | 34.33 | 30.26 | 32.6 | 34.63 | 30.33 | 32.43 | 34.2 | 31.26 | 32.76 | 35.36 |
| Monthly average. | 33.59 | 34.83 | 36.87 | 33.29 | 34.84 | 37.16 | 33.27 | 35.41 | 37.40 | 33.55 | 35.52 | 36.98 | 32.32 | 34.35 | 37.13 |

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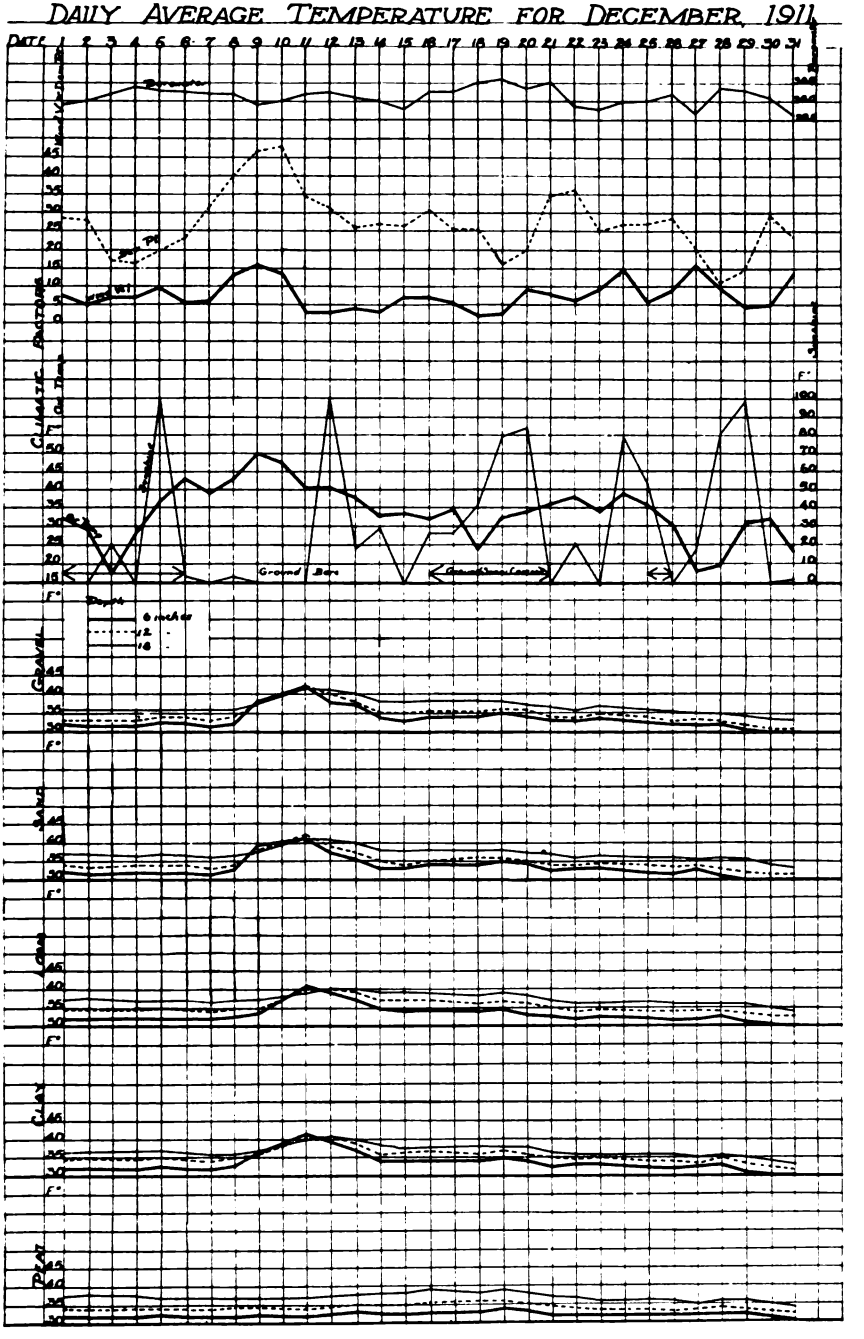


FIG. 4.

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TABLE 19.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, JANUARY, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 8″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 29.36 | 30.53 | 33.46 | 29.16 | 31.4 | 33.16 | 29.93 | 31.96 | 33.83 | 30.1 | 32.36 | 34.26 | 31.46 | 32.36 | 35.16 |
| 2 | 27.5 | 30.43 | 32.86 | 27. | 30.26 | 33.43 | 28.86 | 31.2 | 33.86 | 29.4 | 31.26 | 32.63 | 29.06 | 31.1 | 34.33 |
| 3 | 22.6 | 26.66 | 29.9 | 20.86 | 27.93 | 31.46 | 26.86 | 31.03 | 32.96 | 27.63 | 30.9 | 32.73 | 28.8 | 31.13 | 33.96 |
| 4 | 26.06 | 29.13 | 33.36 | 24.16 | 29.66 | 34.16 | 28.86 | 32.86 | 35.3 | 28.63 | 32.6 | 34.5 | 29.83 | 33.06 | 35.83 |
| 5 | 20.86 | 26.26 | 32.66 | 18.16 | 26.86 | 33.3 | 25.33 | 32.16 | 35. | 25.66 | 31.9 | 33.93 | 25.4 | 32.5 | 35.23 |
| 6 | 19.96 | 24.16 | 31.7 | 14.73 | 24.7 | 32.73 | 23.16 | 31.73 | 34.53 | 23.53 | 31.5 | 33.86 | 21.23 | 32.16 | 35.26 |
| 8 | 20.03 | 23.36 | 29.8 | 16.33 | 23. | 31.4 | 21.86 | 29.53 | 33.56 | 21.7 | 28.86 | 32.6 | 19.63 | 31.73 | 34.06 |
| 9 | 24.23 | 26.26 | 30.23 | 20.96 | 25.6 | 31.46 | 24.33 | 28.8 | 32.63 | 23.46 | 27.8 | 31.66 | 21.66 | 31. | 33.83 |
| 10 | 25.36 | 27.4 | 30.6 | 23.13 | 26.93 | 31.26 | 25.06 | 29.13 | 32.56 | 24.6 | 28.53 | 31.23 | 23.16 | 30.76 | 33.66 |
| 11 | 25.83 | 27.83 | 30.33 | 23.8 | 27.66 | 31.36 | 26.3 | 29.06 | 32.56 | 24.56 | 28.03 | 31.36 | 23.93 | 30.2 | 33.46 |
| 12 | 26.13 | 27.6 | 30.13 | 23.93 | 27.46 | 30.6 | 26.76 | 29.06 | 31.23 | 24.46 | 27.86 | 30.76 | 23.13 | 28.9 | 32.86 |
| 13 | 24.5 | 26.73 | 29.7 | 23.23 | 27.13 | 30.26 | 25. | 28.16 | 31.23 | 22.23 | 27.16 | 30.46 | 21.83 | 27.8 | 32.2 |
| 15 | 25.46 | 27.9 | 30.63 | 24.7 | 27.76 | 30.7 | 25.5 | 28.6 | 31.56 | 24.3 | 27.5 | 30.43 | 24.23 | 28.16 | 32.53 |
| 16 | 25.26 | 27.56 | 30.3 | 23.93 | 27.7 | 30.5 | 25.4 | 28.76 | 31.46 | 24.3 | 27.26 | 30. | 23.3 | 28.2 | 32.33 |
| 17 | 24.76 | 26.83 | 29.73 | 23.9 | 26.9 | 30.1 | 25.26 | 28.7 | 31.06 | 24.66 | 27.13 | 30.03 | 23.4 | 27.96 | 32.16 |
| 18 | 28. | 29.1 | 30.9 | 26.56 | 28.83 | 31.3 | 27.03 | 29. | 31.7 | 26.66 | 28.23 | 30.46 | 26.33 | 28.7 | 32.6 |
| 19 | 29.33 | 29.9 | 30.96 | 28.16 | 29.86 | 31.36 | 27.43 | 29.16 | 31.7 | 27.46 | 28.7 | 30.43 | 26.9 | 28.76 | 32.73 |
| 20 | 27.3 | 28.1 | 30.5 | 25.5 | 28.8 | 30.5 | 26.36 | 28.6 | 30.5 | 26.63 | 28.63 | 29.9 | 25.63 | 28.23 | 31.7 |
| 22 | 27.66 | 28.13 | 30.23 | 26.83 | 28.8 | 30.4 | 26.13 | 28.8 | 30.7 | 27.03 | 28.73 | 29.83 | 25.73 | 27.96 | 31.8 |
| 23 | 28.13 | 29.03 | 30.56 | 27.43 | 29.3 | 30.66 | 27.9 | 28.86 | 30.83 | 27.9 | 27.03 | 30.1 | 26.66 | 28.5 | 31.93 |
| 24 | 28.83 | 29.9 | 31.33 | 28.2 | 30.13 | 31.66 | 28.26 | 29.96 | 31.43 | 28.53 | 29.9 | 30.86 | 27.33 | 29.13 | 32.1 |
| 25 | 28.8 | 29.8 | 31.63 | 27.83 | 30. | 31.63 | 28.06 | 29.96 | 31.56 | 28.36 | 29.7 | 31.03 | 27.06 | 29.03 | 32.16 |
| 26 | 28.56 | 29.53 | 31.3 | 27.36 | 29.93 | 31.43 | 28.03 | 29.93 | 31.53 | 28.2 | 29.96 | 32.3 | 27.06 | 29.16 | 32.3 |
| 27 | 28.93 | 29.9 | 31.2 | 27.63 | 30.1 | 31.6 | 28.1 | 29.9 | 31.36 | 28.53 | 29.86 | 30.76 | 27.23 | 29.3 | 31.96 |
| 29 | 28.2 | 29.03 | 30.63 | 27.13 | 20.06 | 30.93 | 27.53 | 29.03 | 30.83 | 28.03 | 29.16 | 30.16 | 26.73 | 28.66 | 31.43 |
| 30 | 28.03 | 29.03 | 29.86 | 26.93 | 28.26 | 30.43 | 27.1 | 28.5 | 30.23 | 27.73 | 28.63 | 29.73 | 26.6 | 28.1 | 30.76 |
| 31 | 28.93 | 29.63 | 30.53 | 27.9 | 29.26 | 30.96 | 27.96 | 29.03 | 30.86 | 28.53 | 29.03 | 30.03 | 27.53 | 28.9 | 30.9 |
| Monthly average | 26.24 | 28.14 | 30.93 | 24.62 | 28.27 | 31.44 | 26.60 | 29.68 | 32.10 | 26.40 | 29.27 | 31.34 | 25.58 | 29.68 | 32.94 |

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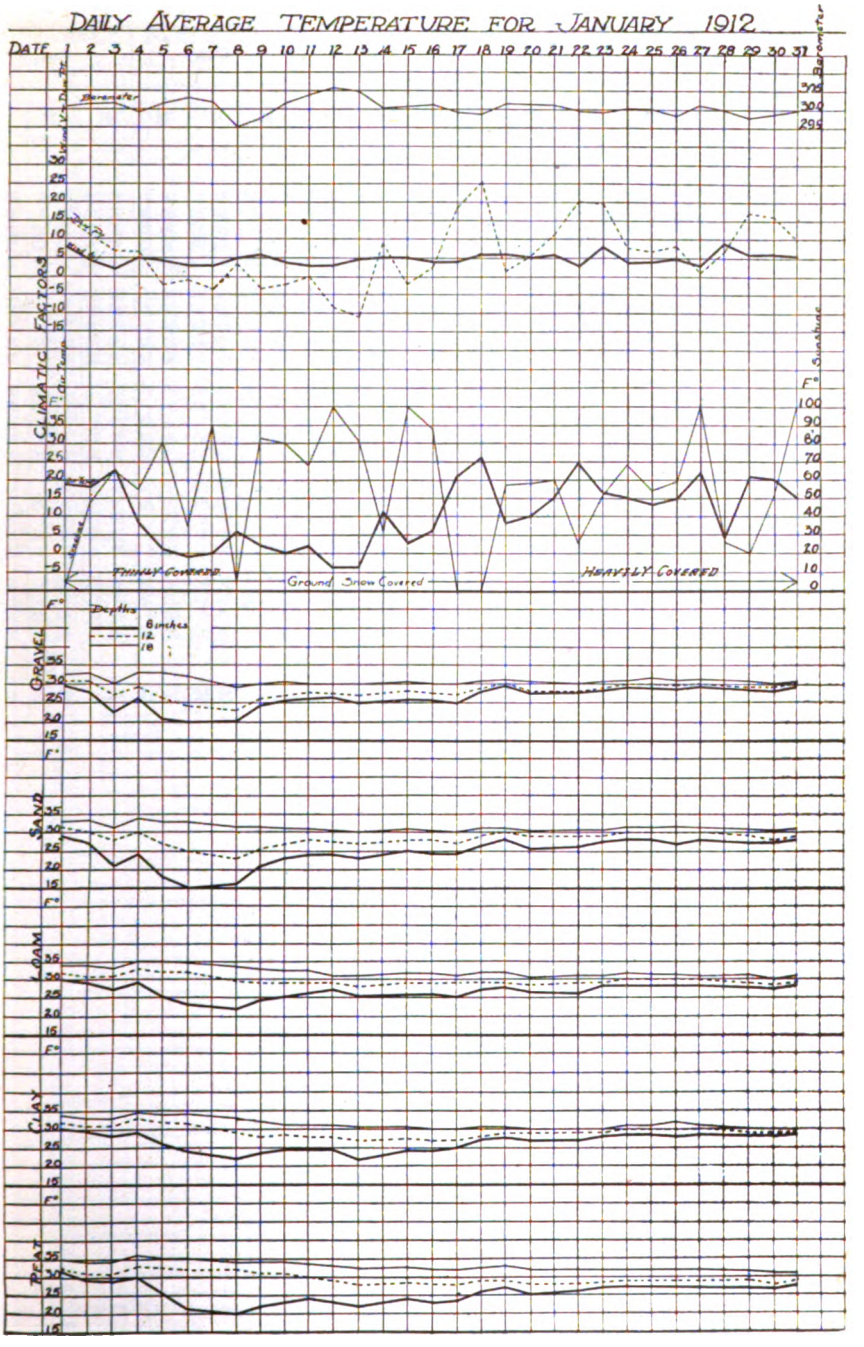


FIG. 5.

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TABLE 20.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, FEBRUARY, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 9″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 28.9 | 29.8 | 30.8 | 27.46 | 29.43 | 31.03 | 28.03 | 29. | 30.86 | 28.33 | 29.2 | 30.3 | 27.23 | 28.8 | 31.13 |
| 2 | 28.86 | 29.9 | 31.1 | 27.53 | 29.56 | 31. | 28.16 | 29.1 | 30.93 | 28.4 | 29.26 | 30.26 | 27.13 | 28.5 | 31.23 |
| 3 | 28.7 | 29.76 | 30.93 | 27.3 | 29.33 | 30.8 | 28.23 | 29.03 | 30.66 | 28.56 | 29.53 | 30.53 | 27.26 | 29.03 | 31.16 |
| 5 | 28.53 | 29.86 | 31.1 | 27.43 | 29.8 | 31.2 | 28.06 | 30. | 30.96 | 28.3 | 29.96 | 30.63 | 27.26 | 28.83 | 31.03 |
| 6 | 28.43 | 29.73 | 31.33 | 27.16 | 29.9 | 31.33 | 28. | 29.86 | 31.53 | 28.63 | 30.33 | 31.03 | 26.96 | 29.13 | 31.86 |
| 7 | 28.43 | 29.93 | 31.06 | 27.03 | 29.8 | 31.16 | 28.06 | 29.6 | 31.4 | 28.56 | 30.03 | 30.9 | 27.03 | 28.96 | 31.9 |
| 8 | 28.3 | 29.33 | 30.53 | 26.96 | 29.8 | 31.1 | 27.53 | 29. | 30.83 | 27.96 | 29.56 | 30.33 | 26.93 | 28.9 | 31.43 |
| 9 | 28.6 | 29.53 | 31.03 | 26.7 | 29.73 | 31.53 | 27.86 | 29.9 | 31.2 | 28.5 | 29.53 | 30.5 | 27.26 | 29.16 | 32. |
| 10 | 27.73 | 28.96 | 30.93 | 23.6 | 28.5 | 31.13 | 26.16 | 29.53 | 30.86 | 26.46 | 29.03 | 30.33 | 26.76 | 28.76 | 31.16 |
| 12 | 28. | 29.03 | 30.93 | 25.13 | 28.2 | 30.7 | 26.16 | 29.16 | 30.9 | 26.3 | 28.9 | 30.16 | 26.36 | 28.6 | 31.56 |
| 13 | 27.66 | 28.93 | 30.6 | 25.23 | 28.1 | 30.43 | 26.66 | 28.53 | 30.46 | 26.03 | 28.93 | 29.9 | 26.73 | 28.53 | 31.2 |
| 14 | 28.03 | 28.93 | 30.63 | 25.56 | 28.53 | 30.3 | 26.2 | 28.4 | 30.66 | 26.33 | 28.43 | 30. | 27. | 28.43 | 31.4 |
| 15 | 28.8 | 29.43 | 30.56 | 26.83 | 29.03 | 30.5 | 26.96 | 28.63 | 30.86 | 27. | 28.7 | 30.03 | 27.4 | 28.6 | 31.26 |
| 16 | 28.93 | 29.5 | 30.3 | 28.03 | 29.3 | 30.3 | 27.2 | 28.4 | 30.2 | 27.43 | 28.83 | 29.43 | 27.83 | 28.8 | 31.06 |
| 17 | 28.63 | 29.1 | 30.06 | 28.06 | 29.1 | 30.16 | 27.33 | 28.2 | 29.6 | 27.3 | 28.53 | 29.36 | 28.23 | 28.96 | 30.93 |
| 19 | 29.8 | 30.1 | 30.7 | 30.26 | 30.43 | 31.16 | 29.5 | 29.53 | 30.23 | 28.66 | 28.66 | 30.06 | 29.5 | 29.7 | 31.03 |
| 20 | 30.4 | 30.83 | 31.4 | 30.93 | 31.1 | 30.33 | 29.33 | 29.96 | 30.83 | 29.7 | 29.83 | 30.76 | 29.96 | 30.06 | 31.13 |
| 22 | 29.3 | 29.5 | 29.6 | 29.4 | 30.1 | 29.2 | 28.7 | 29.5 | 29.9 | 29.8 | 29.6 | 30.1 | 29.7 | 30.5 | 30.2 |
| 23 | 29.45 | 29.95 | 30.65 | 30.2 | 30.35 | 30.93 | 28.85 | 29.55 | 30.45 | 28.85 | 29.8 | 30.4 | 28.55 | 30.05 | 31.4 |
| 24 | 30.25 | 30.95 | 30.8 | 31.15 | 30.85 | 30.8 | 29.95 | 30.3 | 30.65 | 30. | 30.1 | 30.6 | 29.45 | 30.2 | 30.7 |
| 26 | 30.9 | 31.13 | 31.1 | 31.03 | 31 2 | 31.43 | 29.5 | 30.13 | 30.9 | 29.93 | 30.53 | 30.73 | 29.93 | 29.9 | 31.06 |
| 27 | 30.46 | 31.06 | 31.3 | 31 4 | 31.36 | 31.56 | 29.73 | 30.26 | 31.16 | 30.16 | 30.56 | 30.96 | 30.4 | 30.36 | 31.66 |
| 28 | 30.96 | 31.2 | 31.2 | 31.06 | 31.46 | 31.53 | 29.8 | 30.16 | 31. | 30.16 | 30.4 | 30.9 | 30.3 | 30.26 | 31.43 |
| 29 | 31.03 | 31.23 | 31.46 | 31. | 31.23 | 31.53 | 29.96 | 30.46 | 31.2 | 30.5 | 30.66 | 31.26 | 30.7 | 30.43 | 31.4 |
| Monthly average | 29.13 | 29.90 | 31.44 | 28.20 | 29.84 | 30.88 | 28.17 | 29.43 | 30.75 | 28.41 | 29.52 | 30.39 | 28.15 | 29.31 | 31.27 |

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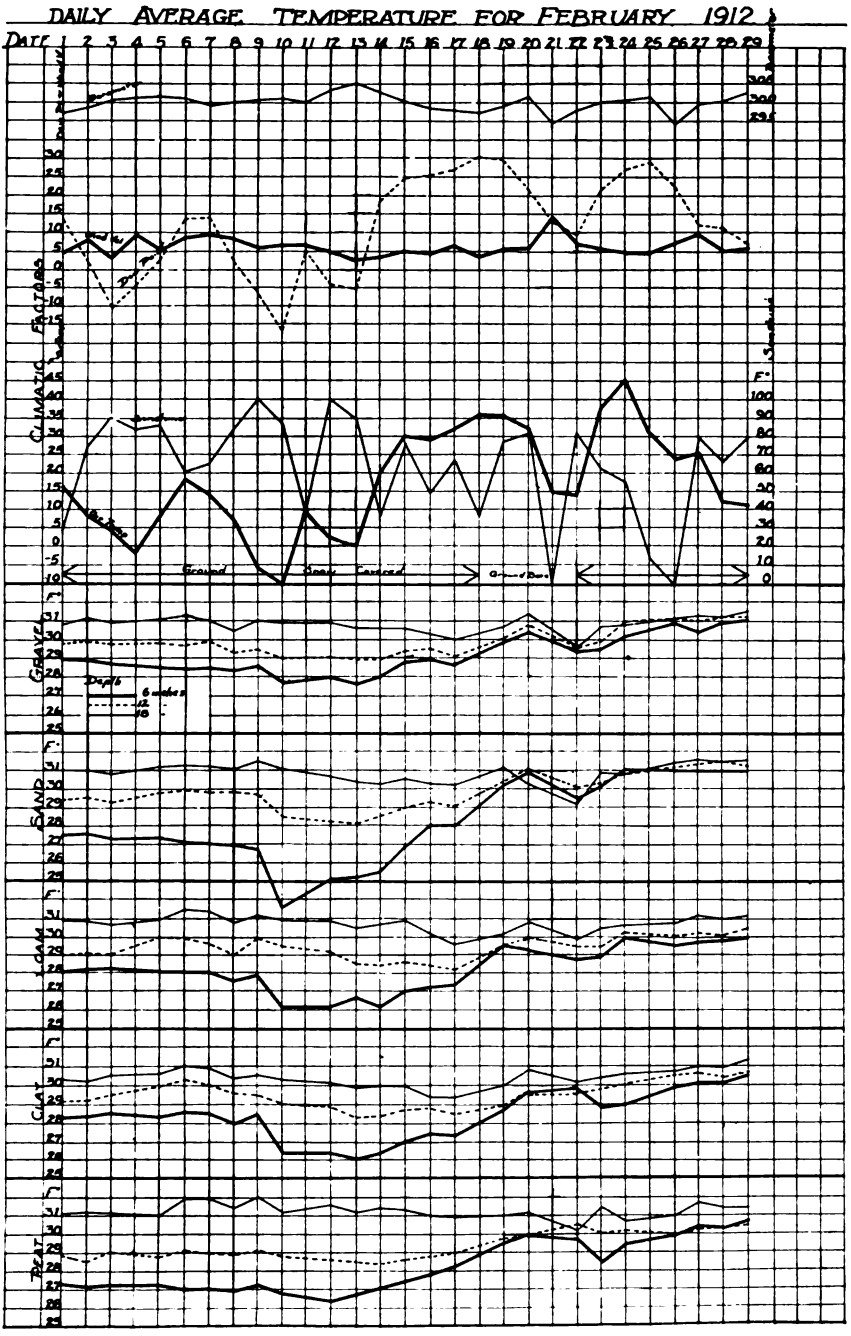


FIG. 6.

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TABLE 21.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, MARCH, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 31. | 31.2 | 31.55 | 31.1 | 31.25 | 31.7 | 29.96 | 30.45 | 31.1 | 30.65 | 30.53 | 31.3 | 30.5 | 30.65 | 31.4 |
| 2 | 30.96 | 31.23 | 31.36 | 31. | 31.43 | 31.86 | 29.96 | 30.5 | 31.3 | 30.43 | 30.93 | 31.46 | 30.36 | 30.8 | 31.73 |
| 4 | 30.86 | 31.03 | 31.46 | 30.9 | 31.13 | 31.86 | 29.8 | 30.93 | 31.4 | 30.5 | 31.03 | 31.56 | 29.83 | 30.4 | 31.6 |
| 5 | 29.95 | 30.6 | 31.35 | 30.35 | 31.1 | 31.9 | 29.45 | 30.85 | 31.2 | 29.7 | 30.9 | 31.15 | 29.3 | 30.25 | 31.35 |
| 6 | 29.25 | 30.15 | 31.15 | 29.55 | 31. | 31.65 | 28.75 | 29.95 | 30.65 | 29.1 | 30. | 30.8 | 28.7 | 29.65 | 31.25 |
| 7 | 29.03 | 30.06 | 31.56 | 29.6 | 31. | 32.03 | 29.03 | 30.16 | 31.3 | 29.7 | 30.5 | 31.16 | 28.06 | 29.83 | 31.3 |
| 8 | 29.03 | 29.76 | 31. | 29.4 | 30.36 | 31.4 | 28.63 | 29.53 | 30.43 | 29.06 | 29.76 | 30.56 | 28.56 | 29.56 | 31.13 |
| 9 | 29.86 | 30.33 | 31.06 | 30.03 | 30.76 | 31.36 | 29.16 | 30. | 30.76 | 29.23 | 29.93 | 30.26 | 28.9 | 29.26 | 31.2 |
| 11 | 30. | 30.53 | 31.53 | 29.96 | 31.13 | 31.76 | 29.23 | 30.13 | 31.03 | 29.96 | 30.53 | 31.2 | 29.6 | 29.9 | 31.43 |
| 12 | 29.56 | 31.1 | 31.03 | 29.56 | 30.76 | 31.3 | 29.26 | 30. | 30.53 | 29.66 | 30.1 | 30.6 | 29.3 | 29.9 | 30.96 |
| 13 | 30.16 | 30.63 | 31.53 | 30.2 | 30.9 | 31.5 | 29.6 | 30.16 | 30.83 | 30. | 30.3 | 31.03 | 29.7 | 30.13 | 31.37 |
| 14 | 29.7 | 29.9 | 30.7 | 29.4 | 30.23 | 31.13 | 29.06 | 29.73 | 30.6 | 29.4 | 29.8 | 30.33 | 28.86 | 29.46 | 30.46 |
| 15 | 30.2 | 30.4 | 31.2 | 30. | 30.3 | 31.2 | 30. | 30.5 | 31.4 | 29.9 | 30.4 | 31.3 | 29.8 | 30.3 | 31. |
| 16 | 29.93 | 30.3 | 30.93 | 29.83 | 30.3 | 31.3 | 29.33 | 29.86 | 30.53 | 30.06 | 30.33 | 30.86 | 29.56 | 29.86 | 30.9 |
| 18 | 30.16 | 30.5 | 30.96 | 30.16 | 30.6 | 31.3 | 29.43 | 30.1 | 30.9 | 29.93 | 30.16 | 30.9 | 29.86 | 29.96 | 31. |
| 19 | 30.33 | 30.63 | 31.03 | 30.5 | 30.83 | 31.46 | 29.63 | 30. | 30.83 | 30.03 | 30.3 | 30.66 | 30.03 | 30. | 31.06 |
| 21 | 28.56 | 29.13 | 30.1 | 29.5 | 29.8 | 30.36 | 28.33 | 28.93 | 29.36 | 28.96 | 29.33 | 29.7 | 28.66 | 29.33 | 30.26 |
| 22 | 28.4 | 29.26 | 30.2 | 29.5 | 30.3 | 30.26 | 28.53 | 29.4 | 29.46 | 29.2 | 29.83 | 29.9 | 29.26 | 29.8 | 30.13 |
| 23 | 29.36 | 30.1 | 30.3 | 29.96 | 30.26 | 31.23 | 29.9 | 29.9 | 29.7 | 30. | 30.4 | 30.33 | 29.93 | 29.66 | 31.2 |
| 25 | 29.7 | 30.21 | 31.36 | 30.3 | 31.2 | 31.5 | 29.73 | 30.3 | 31.13 | 29.96 | 30.43 | 31.1 | 29.9 | 29.93 | 31.4 |
| 26 | 30.36 | 31. | 31.36 | 30.7 | 30.73 | 31.6 | 29.46 | 30.3 | 30.36 | 29.86 | 30.23 | 30.5 | 29.86 | 30.1 | 31.2 |
| 27 | 30.2 | 30.7 | 30.96 | 30.2 | 30.76 | 31.53 | 30.06 | 30.4 | 31.16 | 30.6 | 30.66 | 31.03 | 29.96 | 30.46 | 31.46 |
| 28 | 30.4 | 30.93 | 30.83 | 30.5 | 30.9 | 31.56 | 30. | 30.53 | 30.63 | 30.43 | 3.50 | 30.86 | 29.83 | 30.6 | 31.56 |
| 29 | 30.46 | 30.26 | 30.6 | 30.16 | 30.33 | 30.7 | 29.86 | 30.16 | 30.66 | 30.03 | 30.83 | 30.96 | 30.2 | 30.1 | 30.93 |
| 30 | 30.3 | 30.76 | 30.86 | 30.86 | 30.8 | 31.96 | 30.43 | 30.33 | 30.8 | 30.33 | 30.93 | 31. | 30.76 | 30.53 | 30.93 |
| Monthly average | 29.91 | 30.43 | 31.84 | 30.13 | 30.72 | 31.42 | 29.46 | 30.13 | 30.72 | 29.87 | 30.35 | 30.83 | 29.36 | 30.02 | 31.13 |

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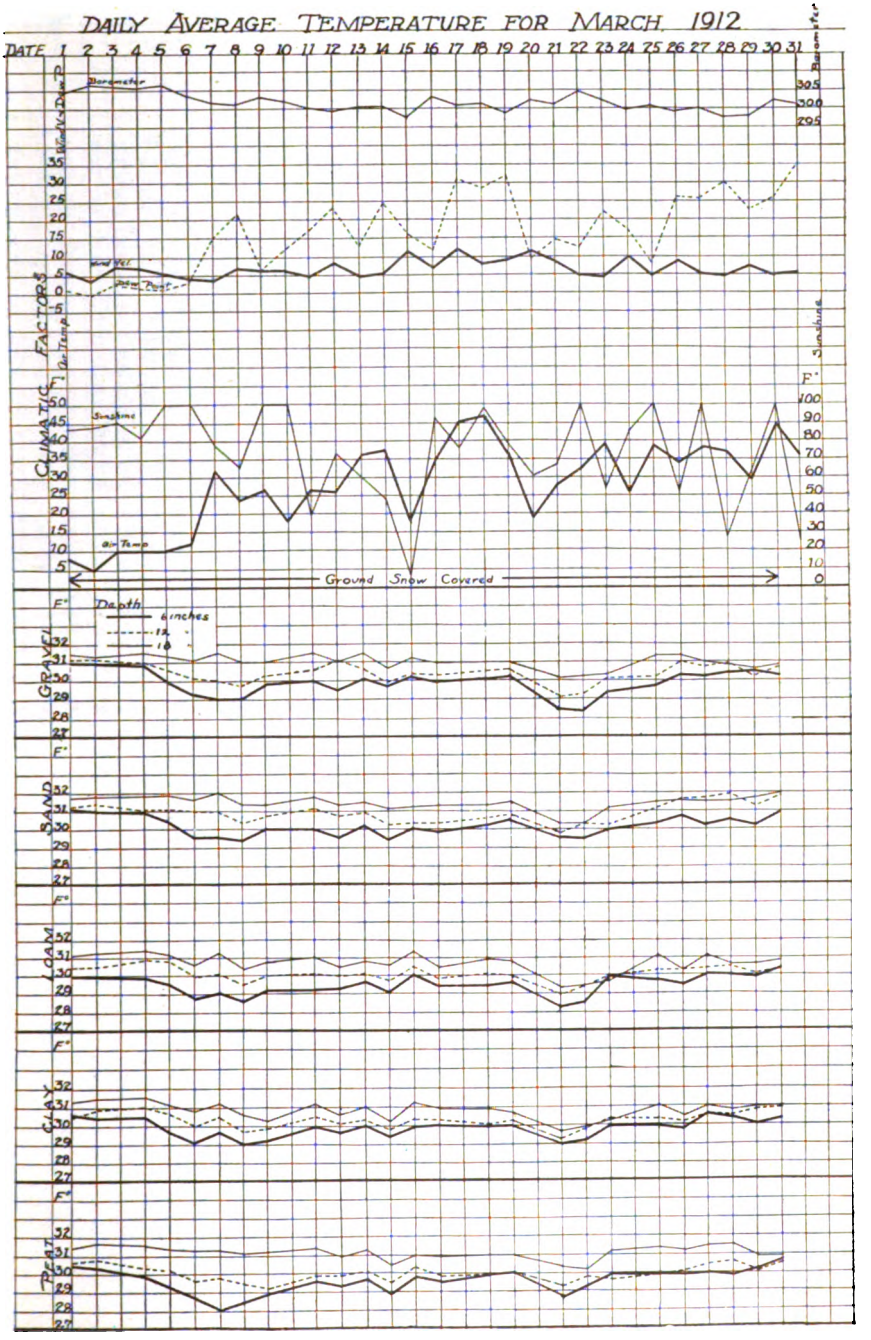


FIG. 7.

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TABLE 22.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, APRIL, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 31.83 | 31.8 | 31.56 | 31.4 | 31.86 | 31.8 | 31.1 | 31.46 | 31.76 | 31.73 | 31.6 | 31.7 | 31.43 | 31.43 | 31.76 |
| 2 | 30.93 | 30.96 | 30.96 | 31.06 | 31.06 | 31.1 | 30.53 | 30.76 | 30.93 | 30.93 | 31. | 30.86 | 30.76 | 30.5 | 31. |
| 3 | 30.06 | 30.33 | 29.93 | 30.06 | 30.16 | 30.06 | 30.36 | 30.9 | 31.1 | 30.86 | 31. | 31.03 | 30.8 | 29.96 | 30.73 |
| 4 | 31.23 | 30.66 | 30.56 | 30.43 | 30.66 | 31.06 | 30.2 | 30.2 | 30.53 | 30.43 | 30.53 | 30.56 | 30.1 | 29.7 | 30. |
| 5 | 35.96 | 32.33 | 31.23 | 33.5 | 30.96 | 31.4 | 30.2 | 30.43 | 30.93 | 31.96 | 30.9 | 30.9 | 30.5 | 30.2 | 30.16 |
| 6 | 40.5 | 36.83 | 31.93 | 38.8 | 33.66 | 31.8 | 30.96 | 30.23 | 30.9 | 35.86 | 30.86 | 30.86 | 30.4 | 30. | 31.06 |
| 7 | 39.93 | 39.66 | 37.0 | 36.83 | 36.20 | 34.63 | 32.46 | 30.16 | 30.9 | 36.16 | 30.80 | 30.76 | 30.40 | 30.10 | 30.96 |
| 8 | 36.1 | 35.6 | 35. | 34.8 | 34.16 | 33.8 | 31.73 | 30.43 | 30.96 | 33.23 | 30.9 | 30.8 | 30.7 | 30.33 | 31.13 |
| 9 | 40.56 | 38.63 | 36.03 | 40.5 | 37.63 | 35.26 | 34.06 | 30.33 | 31. | 36.8 | 31.13 | 30.9 | 30.6 | 30.43 | 31.03 |
| 10 | 42. | 40.53 | 37.86 | 42.26 | 39.8 | 37.46 | 35.2 | 30.46 | 30.86 | 38.13 | 32.46 | 31. | 30.56 | 30.33 | 31.06 |
| 11 | 45.16 | 42.32 | 39.06 | 44.9 | 41.5 | 38.33 | 36.93 | 30.5 | 30.96 | 39.83 | 33.7 | 30.86 | 30.73 | 30.16 | 31.03 |
| 12 | 46.5 | 43.43 | 41.16 | 45.76 | 43.43 | 40. | 38.86 | 31.53 | 30.96 | 42.96 | 37.76 | 34.33 | 30.6 | 30.16 | 30.93 |
| 13 | 45.16 | 44.1 | 41.53 | 44.6 | 43.13 | 40.63 | 38.46 | 32.93 | 31.66 | 43.23 | 39.86 | 37.63 | 30.7 | 30.13 | 30.96 |
| 15 | 47. | 45.43 | 41.93 | 46.6 | 43.9 | 41.03 | 41.86 | 40.36 | 35.03 | 45.63 | 41.5 | 39.23 | 32.83 | 30.93 | 31.2 |
| 16 | 46.43 | 45.83 | 43.53 | 45.86 | 44.73 | 42.86 | 44. | 41.73 | 38.73 | 46.23 | 43.73 | 41.56 | 33.36 | 30.3 | 31.06 |
| 17 | 43.4 | 43.56 | 43.03 | 42.76 | 42.66 | 42.3 | 42.46 | 42.16 | 40.36 | 43.86 | 43.26 | 42.02 | 33.96 | 30.26 | 31.3 |
| 18 | 40.76 | 41.53 | 42. | 40.13 | 40.4 | 40.66 | 40.46 | 41.3 | 40.36 | 41.16 | 41.76 | 41.33 | 33.56 | 30.56 | 31.56 |
| 19 | 40.8 | 40.53 | 40.56 | 40.4 | 40.13 | 39.96 | 39.63 | 40. | 39.9 | 40.63 | 39.93 | 40.1 | 33.1 | 30.36 | 31.66 |
| 20 | 38.96 | 38.13 | 39.66 | 39.66 | 39.4 | 39.83 | 40.93 | 40. | 40.33 | 39.33 | 40.53 | 39.3 | 34.06 | 30.06 | 31.8 |
| 22 | 47.36 | 46.66 | 44.33 | 46.76 | 46.2 | 44.23 | 47.36 | 44.73 | 41.8 | 47.7 | 44.6 | 43.4 | 39.13 | 30.6 | 31.86 |
| 23 | 42.96 | 42.73 | 42.43 | 43.33 | 42.33 | 42.53 | 42.6 | 42.96 | 41.86 | 42.56 | 42.63 | 42.16 | 36.03 | 30.46 | 31.86 |
| 24 | 47.73 | 45.96 | 43.36 | 47.96 | 45.36 | 43.1 | 46.06 | 43.7 | 41.76 | 46.46 | 43.66 | 42.36 | 38.36 | 30.4 | 32. |
| 25 | 47.13 | 46. | 44.03 | 47.2 | 45.16 | 43.56 | 46.6 | 44.4 | 42.23 | 46.53 | 44.7 | 43.23 | 38.86 | 30.56 | 32.03 |
| 26 | 50.43 | 48.66 | 45.8 | 50.73 | 47.8 | 45.1 | 49.43 | 46.5 | 43.63 | 49.83 | 46.2 | 44.8 | 41.73 | 30.8 | 32.7 |
| 27 | 50.73 | 49.36 | 46.46 | 50.83 | 48.9 | 46.56 | 50.46 | 47.76 | 44.56 | 50.83 | 47.46 | 45.7 | 43.36 | 30.96 | 33. |
| 29 | 43.2 | 43.5 | 44.23 | 42.6 | 43.16 | 43.9 | 44.33 | 45.16 | 44.7 | 43.83 | 44.7 | 44.53 | 40.23 | 31.46 | 34.06 |
| 30 | 44.3 | 43.13 | 42.76 | 45.03 | 43.06 | 42.76 | 43.16 | 43.33 | 43.26 | 43.66 | 43.03 | 43.36 | 38.66 | 31.43 | 34.56 |
| Monthly average | 41.81 | 40.70 | 39.27 | 41.48 | 40.64 | 38.92 | 39.16 | 37.47 | 36.58 | 40.29 | 38.44 | 37.48 | 34.64 | 35.48 | 31.59 |

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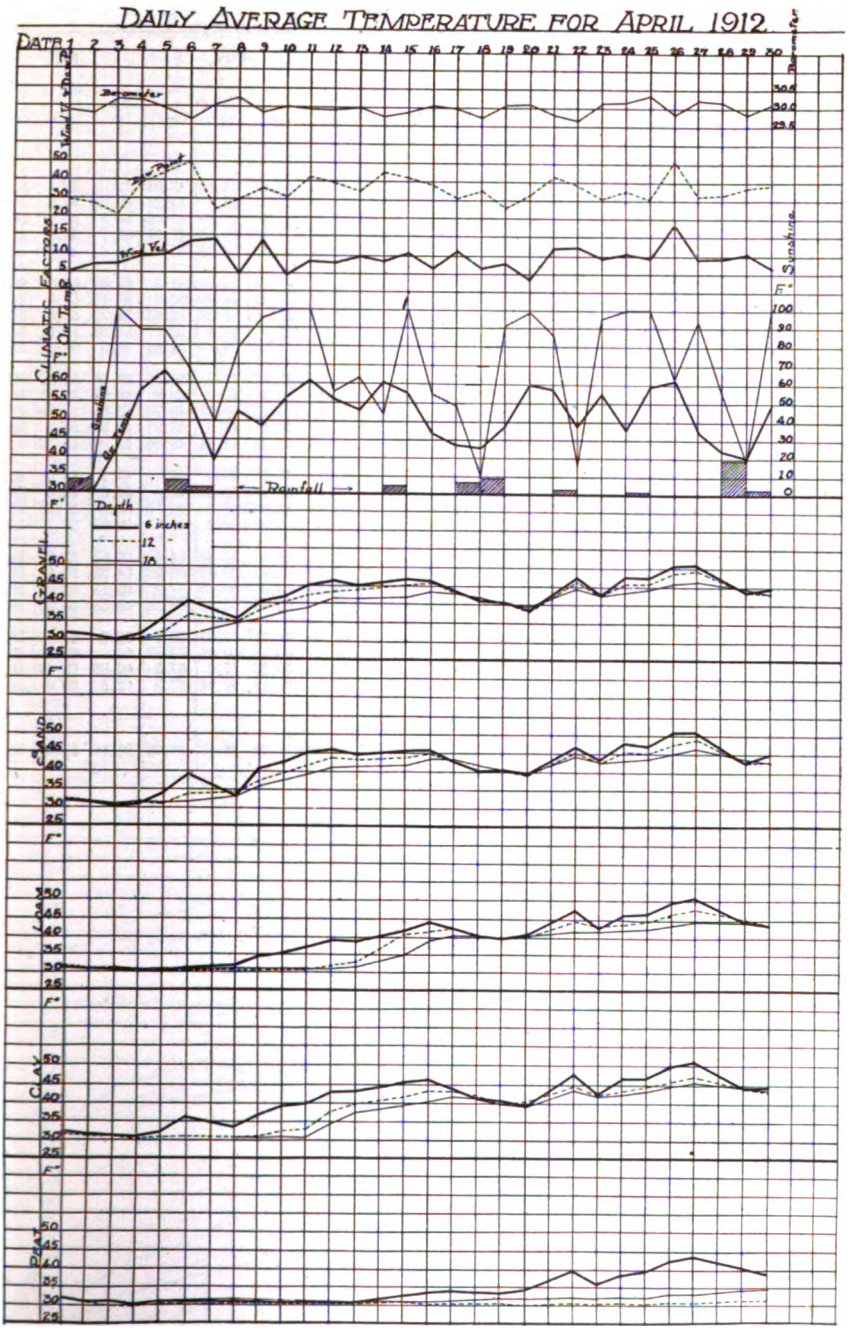


FIG. 8.

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TABLE 23.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOILS, MAY, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 45.56 | 45.53 | 44.63 | 45.73 | 45.53 | 44.53 | 45. | 44.53 | 43.23 | 45.4 | 44.66 | 43.93 | 42. | 32.6 | 35.63 |
| 2 | 48.93 | 46.76 | 44.6 | 49.33 | 46.6 | 44.76 | 46.63 | 44.8 | 43.76 | 47.73 | 45.1 | 44.23 | 42.93 | 34.6 | 36.96 |
| 3 | 53.03 | 50.43 | 46.86 | 53.23 | 49.96 | 47.8 | 50.5 | 46.83 | 44.6 | 52.03 | 47.83 | 45.66 | 47.5 | 38.7 | 39.66 |
| 4 | 55. | 52.53 | 48.53 | 55.13 | 52.23 | 48.13 | 53.33 | 49.33 | 46.03 | 54.46 | 49.83 | 47.76 | 51.2 | 44.5 | 42.86 |
| 6 | 57.8 | 54.76 | 50.6 | 57.46 | 54.16 | 50.46 | 55.66 | 52.16 | 48.56 | 57.13 | 52.36 | 50. | 55.6 | 49.7 | 46.96 |
| 7 | 60.10 | 57.36 | 52.7 | 60.03 | 56.83 | 52.16 | 59. | 54.36 | 49.86 | 60.13 | 54.76 | 51.8 | 58.86 | 52.03 | 48.66 |
| 8 | 57.2 | 55.96 | 53.1 | 56.73 | 55.03 | 52.66 | 57.6 | 55.16 | 50.96 | 57.93 | 54.96 | 52.9 | 59.43 | 54.1 | 49.93 |
| 9 | 55.03 | 54.06 | 52.26 | 54.86 | 53.23 | 51.73 | 54.83 | 53.96 | 51.33 | 55.66 | 54.26 | 52.63 | 57.76 | 54.63 | 51.66 |
| 10 | 57. | 54.9 | 52.13 | 57.33 | 54.33 | 51.76 | 55.83 | 53.4 | 50.8 | 56.9 | 53.8 | 52. | 57.53 | 54.4 | 51.66 |
| 11 | 57.36 | 55.63 | 52.66 | 55.83 | 54.86 | 52.5 | 56.66 | 54.4 | 50.63 | 57.06 | 54.63 | 52.33 | 58.9 | 54.93 | 51.83 |
| 13 | 46.8 | 47.2 | 48.6 | 47.83 | 47.63 | 48.76 | 48.23 | 50.03 | 50.06 | 47.83 | 49.5 | 50.53 | 50.76 | 53.66 | 52.76 |
| 14 | 49.93 | 48.93 | 48.3 | 50.93 | 49.33 | 49.06 | 49.33 | 49.13 | 48.53 | 50.2 | 49.2 | 49.2 | 51.03 | 51.56 | 51.4 |
| 15 | 47.8 | 48.23 | 48.7 | 47.3 | 48.23 | 49.4 | 48.4 | 49.36 | 49 | 49.33 | 49.93 | 49.76 | 50.56 | 51.36 | 51.16 |
| 16 | 48.06 | 48.03 | 48.03 | 47.9 | 48. | 48.56 | 48.26 | 48.66 | 48.46 | 48.8 | 48.9 | 48.93 | 49.53 | 50.3 | 50.6 |
| 17 | 49.93 | 48.33 | 47.6 | 47.1 | 48.3 | 47.53 | 48.26 | 48. | 47.53 | 49.33 | 48.03 | 48.06 | 48.96 | 49.13 | 49.33 |
| 18 | 48.1 | 47.9 | 47.85 | 49.65 | 48.8 | 47.8 | 49.2 | 48.35 | 47.1 | 49.15 | 48.6 | 48.15 | 49.2 | 48.65 | 49.05 |
| 20 | 52.8 | 51.26 | 49.8 | 52.6 | 50.96 | 49.86 | 51.16 | 49.96 | 49.03 | 52.46 | 50.83 | 49.8 | 51.6 | 49.8 | 49.26 |
| 21 | 56. | 53.93 | 50.83 | 56.66 | 53.33 | 50.76 | 54.06 | 51.26 | 49.33 | 55.26 | 51.8 | 50.73 | 53.8 | 51.36 | 49.53 |
| 22 | 60.06 | 57.1 | 53.06 | 61.6 | 56.8 | 53.1 | 57.56 | 53.5 | 50.8 | 59.03 | 54.4 | 52.43 | 56.93 | 52.5 | 50.73 |
| 23 | 64.4 | 60.73 | 55.5 | 65.76 | 60.6 | 55.76 | 61.06 | 56.1 | 52.16 | 63.1 | 57.46 | 54.43 | 60.83 | 53.83 | 51.66 |
| 24 | 65.53 | 62.93 | 58.3 | 65.53 | 62.23 | 57.63 | 63.8 | 59.16 | 54.16 | 65.43 | 60.33 | 56.96 | 64.23 | 57.8 | 54.43 |
| 25 | 63.9 | 60.9 | 57.53 | 64. | 60.26 | 57.2 | 61.63 | 58.8 | 55.36 | 63.46 | 59.66 | 57.2 | 63.13 | 58.63 | 54.96 |
| 27 | 65.6 | 63.83 | 60. | 65.26 | 62.76 | 59.5 | 65.1 | 61.6 | 57. | 65.93 | 62.16 | 59.26 | 65.83 | 60.83 | 56.83 |
| 28 | 64.16 | 62.86 | 59.7 | 63.53 | 62.1 | 59.46 | 64.56 | 61.5 | 57.86 | 64.86 | 62.03 | 59.7 | 66.3 | 61.76 | 58.06 |
| 29 | 59.3 | 59.66 | 58.86 | 58.48 | 58.86 | 58.53 | 61.06 | 60.80 | 58.06 | 60.76 | 60.63 | 59.43 | 64. | 62.33 | 59.16 |
| 30 | 59.93 | 58. | 56.4 | 60.93 | 57.86 | 56.46 | 58.6 | 57.63 | 56.73 | 59.26 | 57.6 | 57.3 | 60.86 | 60.43 | 58.9 |
| 31 | 64.3 | 61.3 | 58. | 64.86 | 61.26 | 58.13 | 61.8 | 58.86 | 56.5 | 63.13 | 59.46 | 57.8 | 62.5 | 60.4 | 58.16 |
| Monthly average | 56.07 | 54.41 | 52.03 | 56.11 | 54.08 | 52.00 | 55.07 | 53.02 | 50.02 | 56.00 | 53.43 | 51.08 | 55.61 | 52.60 | 50.44 |

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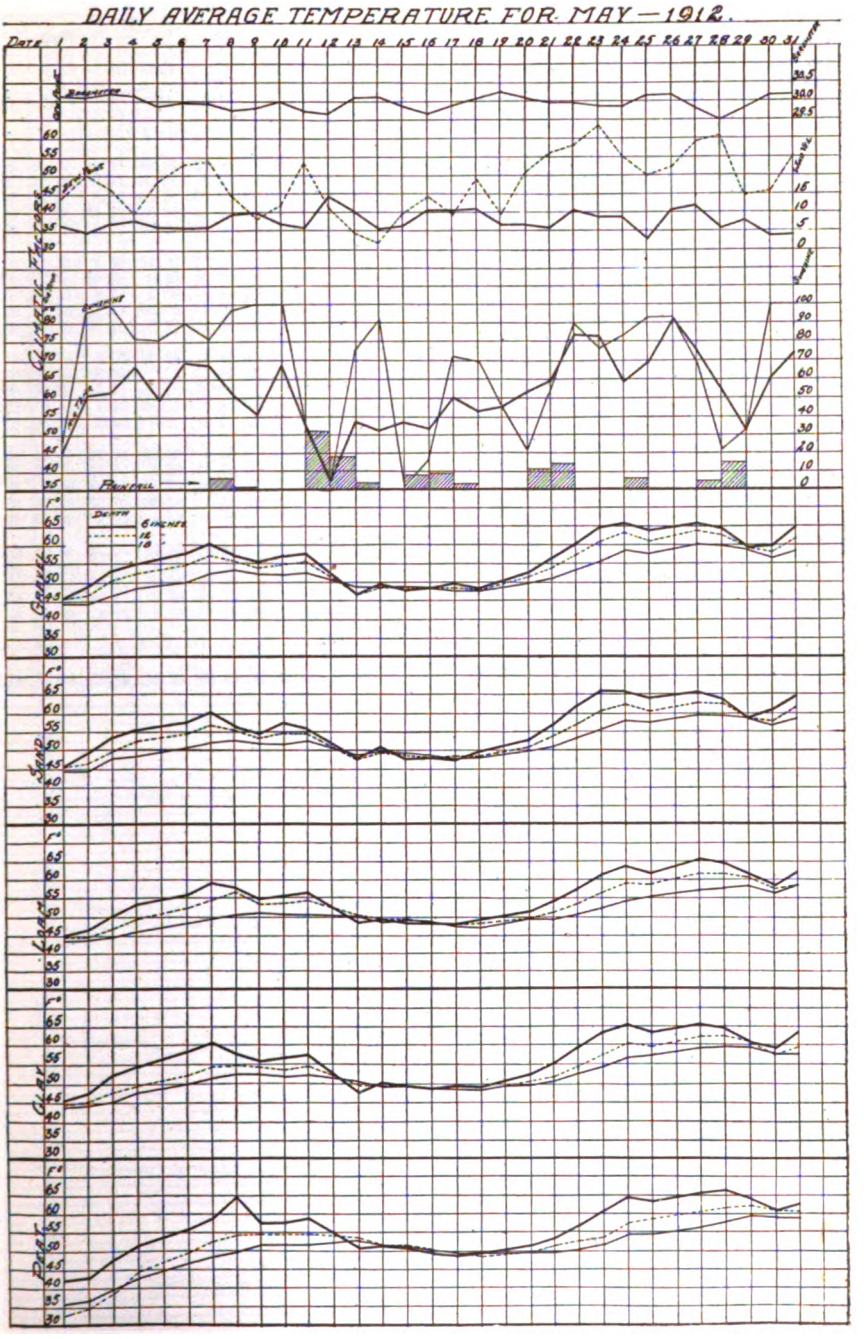


FIG. 9.



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TABLE 24.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, JUNE, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1..... | 67.5 | 64.23 | 59.73 | 67.2 | 63.3 | 59.63 | 64.23 | 61.1 | 57.1 | 66.1 | 61.63 | 59.26 | 65.53 | 60.96 | 58.3 |
| 3..... | 64.76 | 62.4 | 59.76 | 64.86 | 61.76 | 59.56 | 63.43 | 61.36 | 58.66 | 64.3 | 61.6 | 60.06 | 64.9 | 62.13 | 59.4 |
| 4..... | 64.53 | 63.06 | 60.56 | 64.13 | 62.43 | 60.23 | 64.06 | 62.26 | 58.93 | 64.66 | 62.33 | 60.53 | 66.3 | 62.8 | 59.9 |
| 5..... | 61.9 | 60.56 | 59.4 | 61.6 | 60.73 | 59.2 | 61.13 | 60.5 | 58.73 | 62.06 | 60.86 | 59.93 | 63.93 | 62.56 | 60.13 |
| 6..... | 65.8 | 63.2 | 60. | 65.66 | 62.76 | 59.9 | 63.5 | 60.93 | 58.33 | 64.86 | 61.56 | 59.86 | 64.8 | 62.1 | 60.03 |
| 7..... | 63.6 | 62.13 | 60.26 | 63. | 61.23 | 59.7 | 62.5 | 61.26 | 58.8 | 63.5 | 61.76 | 60.16 | 63.9 | 62.16 | 60.1 |
| 8..... | 63.23 | 61.86 | 59.96 | 62.5 | 60.9 | 59.46 | 62.2 | 60.76 | 58.66 | 62.76 | 61.06 | 59.9 | 63.43 | 61.93 | 60.06 |
| 10..... | 65.7 | 63.4 | 60.66 | 64.53 | 62.73 | 60.36 | 64.23 | 61.66 | 59. | 64.93 | 61.83 | 60.5 | 64.9 | 62.16 | 60.16 |
| 11..... | 66.4 | 64.26 | 61.3 | 65.73 | 63.3 | 60.8 | 64.93 | 62.36 | 59.66 | 64.7 | 62.43 | 60.86 | 65.43 | 62.26 | 60.06 |
| 12..... | 68.53 | 66.23 | 62.4 | 68.16 | 65.43 | 62.13 | 67.5 | 63.93 | 60.43 | 67.96 | 63.9 | 61.8 | 67.56 | 63.03 | 60.36 |
| 13..... | 67.46 | 65.4 | 62.56 | 66.46 | 64.26 | 62. | 66.56 | 64.13 | 60.93 | 66.63 | 64.1 | 62.23 | 67.1 | 63.9 | 61.06 |
| 14..... | 64.6 | 64.56 | 62.93 | 63.6 | 63.26 | 62.2 | 65.43 | 64.33 | 61.43 | 65.13 | 64.23 | 62.7 | 66.8 | 64.16 | 61.9 |
| 15..... | 65.9 | 63.73 | 61.4 | 65.86 | 63.26 | 60.96 | 64.9 | 62.5 | 60.56 | 65.3 | 62.53 | 61.33 | 65.36 | 63.26 | 61.6 |
| 17..... | 67.06 | 65.23 | 62.86 | 66.86 | 64.73 | 62.46 | 66.23 | 64.23 | 61.36 | 66.6 | 64.1 | 62.53 | 67.7 | 64.6 | 62. |
| 18..... | 65.33 | 64.2 | 62.6 | 64.6 | 63.3 | 62.03 | 65.06 | 63.83 | 61.26 | 65.03 | 63.8 | 62.5 | 66.5 | 64.56 | 62.06 |
| 19..... | 66.66 | 64.9 | 62.5 | 66.13 | 64.03 | 61.9 | 65.8 | 63.53 | 61.03 | 64.9 | 63.5 | 62.06 | 66.26 | 64.06 | 62.1 |
| 20..... | 66.26 | 64.63 | 62.5 | 65.7 | 63.76 | 61.93 | 65.46 | 63.53 | 61.16 | 65.63 | 63.43 | 62.1 | 66.13 | 64.03 | 62.03 |
| 21..... | 67.13 | 65.43 | 63.1 | 66.5 | 64.5 | 62.46 | 66.33 | 64.16 | 61.86 | 66.33 | 64.03 | 62.56 | 66.96 | 64.3 | 62.3 |
| 22..... | 68.06 | 66.13 | 63.36 | 67.26 | 64.96 | 62.9 | 67.06 | 64.56 | 61.93 | 66.96 | 64.4 | 62.96 | 67.36 | 64.73 | 62.4 |
| 24..... | 70.46 | 68.76 | 65.53 | 69.33 | 67.33 | 64.76 | 70.0 | 66.73 | 63.16 | 69. | 66.4 | 64.4 | 70.2 | 66.16 | 62.06 |
| 25..... | 71.6 | 69. | 65.56 | 70.23 | 67.53 | 64.73 | 70.26 | 66.8 | 63.7 | 70.53 | 66.6 | 64.73 | 70.33 | 66.66 | 63.83 |
| 26..... | 72.73 | 70.43 | 66.73 | 71.03 | 68.8 | 65.63 | 71.66 | 68.06 | 64.13 | 71.33 | 67.7 | 65.4 | 71.93 | 67.53 | 64.13 |
| 27..... | 71.6 | 69.93 | 66.83 | 70.26 | 68.4 | 65.8 | 71.2 | 68.43 | 64.9 | 70.9 | 68.03 | 65.93 | 71.93 | 68.36 | 65.03 |
| 28..... | 72.33 | 69.86 | 66.66 | 70.73 | 68.33 | 65.7 | 71.53 | 68.26 | 64.9 | 71.23 | 67.86 | 65.9 | 72.06 | 68.56 | 65.36 |
| 29..... | 72.33 | 70. | 66.56 | 71.06 | 68.66 | 65 56 | 71.6 | 68.1 | 64.46 | 71.53 | 67.76 | 65.6 | 72.4 | 68.2 | 64.83 |
| Monthly average... | 67.25 | 65.33 | 62.61 | 68.52 | 64.30 | 62.98 | 68.28 | 63.89 | 61.89 | 68.51 | 63.89 | 62.24 | 67.15 | 64.24 | 61.64 |

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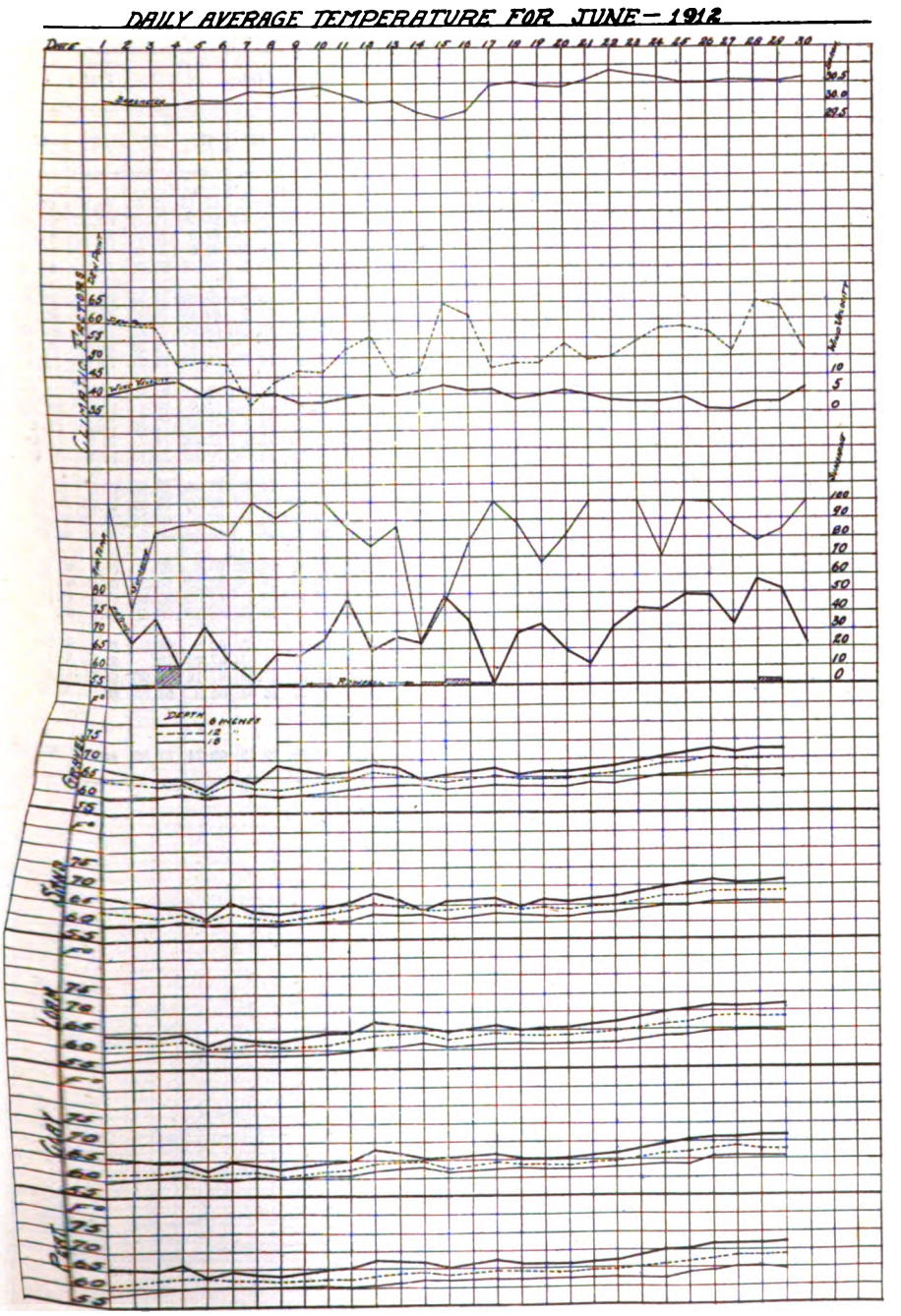


FIG. 10.

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TABLE 25.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOILS, JULY, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 71.33 | 69.66 | 67.46 | 69.63 | 68. | 66.23 | 70.9 | 69.73 | 65.8 | 70.53 | 68.8 | 67.13 | 72.43 | 70.2 | 66.6 |
| 2 | 72.73 | 70.46 | 67.23 | 71.26 | 68.76 | 66.06 | 71.9 | 68.8 | 65.4 | 71.53 | 68.33 | 66.26 | 72.76 | 69.53 | 66.66 |
| 3 | 75.13 | 72.66 | 69.06 | 73.3 | 70.86 | 67.86 | 74.26 | 70.6 | 66.73 | 74.06 | 70.16 | 67.9 | 75.03 | 70.73 | 67.2 |
| 4 | 75.1 | 72.43 | 68.76 | 73.16 | 70.56 | 67.6 | 74. | 70.46 | 66.4 | 73.9 | 69.96 | 67.7 | 74.83 | 70.5 | 66.73 |
| 5 | 76.66 | 74.2 | 70.2 | 74.93 | 72.36 | 68.73 | 76.06 | 71.76 | 67.33 | 75.56 | 71.2 | 68.56 | 76.36 | 71.3 | 67.16 |
| 6 | 77.3 | 75. | 71.2 | 75.56 | 73.23 | 69.93 | 76.96 | 73.1 | 68.73 | 76.33 | 72.26 | 69.63 | 77.23 | 72.6 | 68.26 |
| 8 | 75.56 | 73.26 | 70.23 | 74.76 | 72.13 | 69.4 | 75.1 | 72.1 | 68.83 | 74.9 | 71.6 | 69.83 | 76.36 | 73.03 | 69.7 |
| 9 | 77.63 | 74 63 | 70.93 | 76.36 | 73.26 | 69.93 | 76.36 | 72.46 | 68.76 | 76.23 | 72.03 | 69.96 | 77.23 | 73.13 | 69.53 |
| 10 | 78.73 | 76.63 | 72.73 | 77.2 | 75.16 | 71.76 | 78.33 | 74.4 | 70.13 | 77.23 | 74. | 71.4 | 79.23 | 74.33 | 70.43 |
| 11 | 79.26 | 76.8 | 73.33 | 77.4 | 75.13 | 72.16 | 78.86 | 75.06 | 71.06 | 76.93 | 74.73 | 72.23 | 79.33 | 75.36 | 71.5 |
| 12 | 77.9 | 76.26 | 73.36 | 76.16 | 74.46 | 72.2 | 77.43 | 75.26 | 71.26 | 77.03 | 74.4 | 72.2 | 78.83 | 75.73 | 71.9 |
| 13 | 75.06 | 74.86 | 73.2 | 73.96 | 73.63 | 72.06 | 76.46 | 75.13 | 71.63 | 75.33 | 74.16 | 72.5 | 78.1 | 75.7 | 72.23 |
| 15 | 77.16 | 75.13 | 72.13 | 77.16 | 74.8 | 71.66 | 76.36 | 73.5 | 70.2 | 77.1 | 73.5 | 71.33 | 77.26 | 74.16 | 71.4 |
| 16 | 72.66 | 71.73 | 71.06 | 71.6 | 70.73 | 70.3 | 73.13 | 72.76 | 70.5 | 72.86 | 72.3 | 71.36 | 74.7 | 73.9 | 71.46 |
| 17 | 76.53 | 74.1 | 71.43 | 76. | 73.3 | 70.8 | 75.43 | 72.56 | 69.86 | 75.26 | 72.16 | 70.66 | 75.73 | 73.16 | 70.93 |
| 18 | 72.63 | 72.93 | 72.16 | 71.03 | 71.63 | 71.26 | 74.1 | 73.5 | 70.5 | 72.9 | 72.83 | 71.46 | 75.83 | 73.9 | 71.13 |
| 19 | 66.43 | 66.5 | 67.66 | 65.8 | 65.83 | 66.9 | 67.8 | 69.56 | 69. | 67.13 | 68.56 | 69.03 | 70.23 | 71.96 | 70.63 |
| 20 | 65.36 | 66. | 66.73 | 64.63 | 65.53 | 66.43 | 67.1 | 68.16 | 67.23 | 66.53 | 67.56 | 67.5 | 69.56 | 70.33 | 69.60 |
| 22 | 66.53 | 65.2 | 64.66 | 67.16 | 65.3 | 64.6 | 65.86 | 65.3 | 64.9 | 66.23 | 65. | 65.06 | 66.3 | 66.93 | 66.96 |
| 23 | 67.33 | 66.6 | 65.86 | 68. | 66.96 | 66.06 | 67.13 | 66.1 | 64.86 | 67.83 | 66.33 | 65.6 | 67.7 | 66.7 | 66.13 |
| 24 | 70. | 68.03 | 66.06 | 70.23 | 68.06 | 66.1 | 68.6 | 66.5 | 65.06 | 69.43 | 66.76 | 65.83 | 68.2 | 66.53 | 65.73 |
| 25 | 72.6 | 70.46 | 67.86 | 73.06 | 70.56 | 65.9 | 71.26 | 68.4 | 65 93 | 72.23 | 68.7 | 67.03 | 70.93 | 67.8 | 66.16 |
| 26 | 69.96 | 69.3 | 68.33 | 69.86 | 69.16 | 68.23 | 70.06 | 69.26 | 66.83 | 70.7 | 69.46 | 68.13 | 70.53 | 69.4 | 67. |
| 27 | 69.43 | 67.8 | 66.53 | 69.2 | 67.36 | 66.33 | 68.76 | 67.63 | 65.86 | 69.3 | 67.63 | 66.8 | 68.8 | 68. | 66.63 |
| 29 | 68.33 | 68. | 67.3 | 67.86 | 67.36 | 67.3 | 69.16 | 68.8 | 67.06 | 68.93 | 68.05 | 67.73 | 70. | 69.23 | 67.8 |
| 30 | 66.7 | 66.53 | 66.46 | 66.36 | 66.36 | 66.43 | 67.43 | 67.6 | 66.56 | 67.6 | 67.53 | 67.16 | 68.96 | 68.96 | 67.86 |
| 31 | 65.66 | 65.36 | 65.6 | 65.43 | 65. | 65.46 | 66. | 66.4 | 65.9 | 66.13 | 66.33 | 66.2 | 67.53 | 68. | 67.43 |
| Monthly average... | 72.56 | 71.11 | 69.16 | 71.74 | 70.29 | 68.49 | 72.49 | 70.55 | 67.86 | 72.29 | 70.15 | 68.74 | 73.39 | 68.58 | 68.78 |

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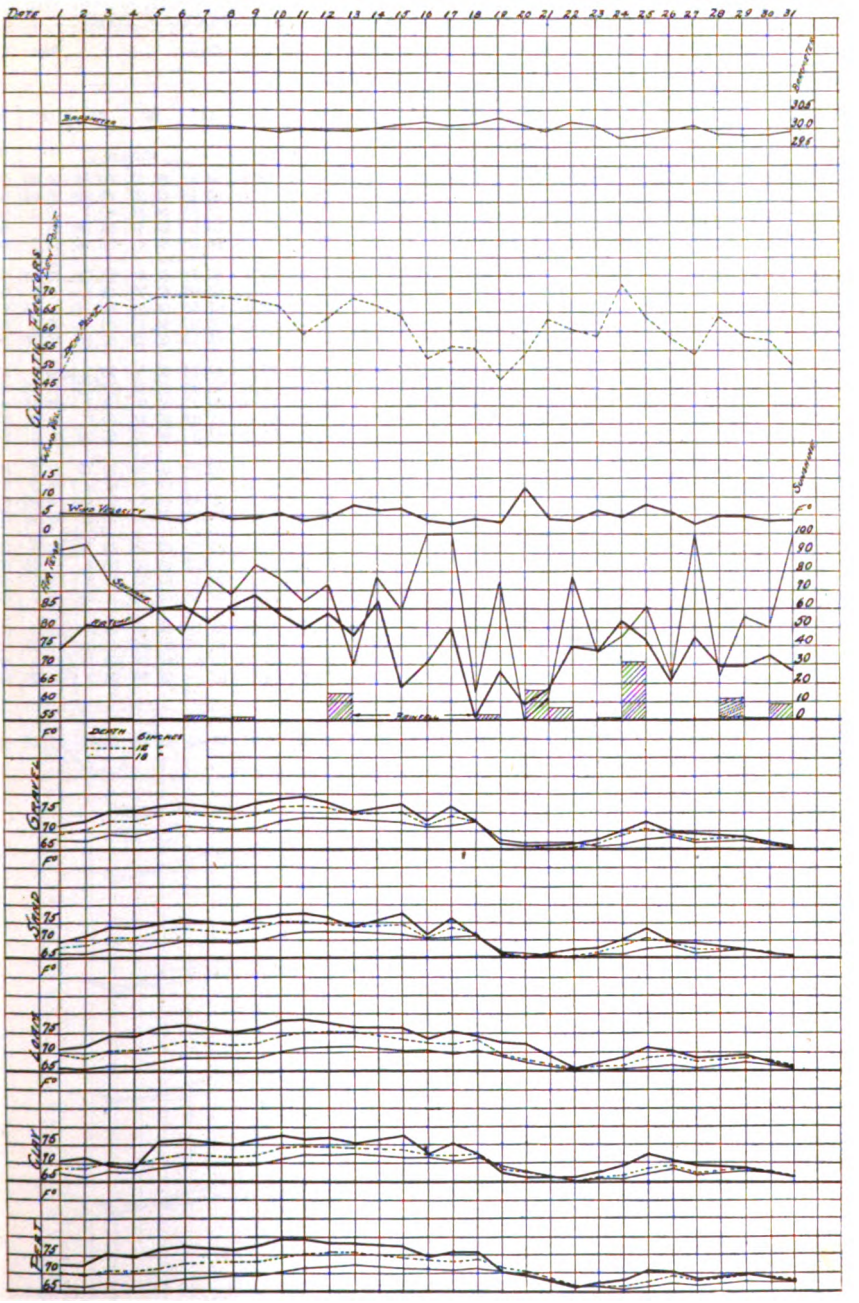


FIG. 11.

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TABLE 26.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, AUGUST, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 65.1 | 64.53 | 64.83 | 65.23 | 64.66 | 64.86 | 64.86 | 65.36 | 65.03 | 65.63 | 65.5 | 65.53 | 66.36 | 66.93 | 66.6 |
| 2 | 65.13 | 65.0 | 64.93 | 64.53 | 64.63 | 64.86 | 65.33 | 65.3 | 64.53 | 65.53 | 65.43 | 65.23 | 65.96 | 66.06 | 66.0 |
| 3 | 61.1 | 61.73 | 63.26 | 60.66 | 61.43 | 63. | 62.13 | 63.8 | 63.93 | 61.9 | 63.53 | 64.86 | 63.7 | 65.3 | 65.4 |
| 5 | 66.43 | 64.9 | 63.73 | 66.66 | 64.83 | 63.76 | 64.96 | 63.73 | 62.86 | 65.76 | 63.9 | 63.43 | 64.86 | 64. | 64.13 |
| 6 | 67.96 | 66.56 | 65.03 | 67.9 | 66.33 | 64.96 | 66.9 | 65.13 | 63.6 | 67.36 | 65.36 | 64.4 | 66.46 | 64.7 | 64.06 |
| 7 | 69.43 | 68.03 | 66.03 | 69.4 | 67.7 | 65.96 | 68.53 | 66.36 | 64.53 | 69.0 | 66.53 | 65.36 | 68.03 | 65.56 | 64.6 |
| 8 | 69.76 | 68.2 | 66.26 | 69.73 | 67.86 | 66.06 | 68.96 | 67.0 | 65. | 69.36 | 67.06 | 65.93 | 68.8 | 66.3 | 64.96 |
| 9 | 69.53 | 68.43 | 66.6 | 69.33 | 67.93 | 66.76 | 69.36 | 67.43 | 65.13 | 69.63 | 67.86 | 66.06 | 69.73 | 66.66 | 65. |
| 10 | 67.66 | 67. | 66.2 | 67.56 | 66.7 | 65.5 | 68.03 | 67.2 | 65.43 | 68.03 | 66.93 | 66.13 | 68.86 | 67.2 | 65.8 |
| 12 | 67.73 | 66.4 | 65.13 | 68.06 | 66.23 | 65.03 | 67.1 | 65.9 | 64.63 | 67.4 | 65.73 | 65.23 | 67.66 | 66.56 | 65.73 |
| 13 | 71.0 | 69.03 | 66.46 | 72.03 | 69.20 | 66.53 | 69.6 | 66.86 | 64.83 | 70.6 | 67.13 | 65.8 | 70.1 | 66.9 | 65.43 |
| 14 | 72.66 | 70.73 | 68.16 | 72.8 | 70.43 | 67.86 | 71.36 | 68.66 | 65.86 | 72.26 | 68.96 | 67.13 | 71.73 | 68.13 | 65.93 |
| 15 | 69.96 | 69.5 | 68.43 | 69.46 | 68.76 | 67.9 | 70.3 | 69.3 | 66.73 | 70.26 | 69.2 | 67.9 | 71.1 | 69.16 | 66.66 |
| 16 | 68.83 | 68.0 | 67.2 | 68.26 | 67.3 | 65.03 | 68.9 | 68.33 | 66.53 | 68.63 | 68.03 | 67.26 | 69.6 | 68.9 | 67.1 |
| 17 | 67.33 | 67.2 | 66.86 | 66.73 | 66.5 | 66.43 | 67.9 | 67.8 | 66.1 | 67.36 | 67.3 | 66.83 | 68.93 | 68.3 | 67.0 |
| 19 | 70.13 | 69.33 | 67.76 | 69.63 | 68.8 | 67.46 | 70.3 | 68.53 | 66.03 | 69.73 | 68.36 | 66.96 | 70.73 | 68.2 | 66.6 |
| 20 | 69.86 | 68.50 | 67.06 | 69.93 | 67.9 | 66.76 | 69.3 | 67.9 | 66.1 | 69.23 | 67.7 | 66.83 | 69.8 | 68.3 | 66.66 |
| 21 | 70.13 | 68.9 | 67.63 | 70.66 | 68.96 | 67.63 | 69.83 | 68.63 | 66.46 | 70.1 | 68.43 | 67.3 | 70.46 | 68.86 | 67.26 |
| 22 | 69.7 | 69.2 | 68.46 | 69.56 | 69.06 | 68.4 | 70. | 69.2 | 67.33 | 70.13 | 69.23 | 68.23 | 70.63 | 69.43 | 67.96 |
| 23 | 66.43 | 66.4 | 66.86 | 65.73 | 66.1 | 66.93 | 67.1 | 68.0 | 66.9 | 66.93 | 67.7 | 67.56 | 68.26 | 69.0 | 67.66 |
| 24 | 66.46 | 65.26 | 65.23 | 66.4 | 65.0 | 65.13 | 65.7 | 66.03 | 65.63 | 66.0 | 65.73 | 65.86 | 66.1 | 67.36 | 67.26 |
| 26 | 75.3 | 73. | 69.63 | 75.1 | 72.56 | 69.43 | 73.7 | 69.96 | 66.56 | 74.16 | 70.1 | 67.93 | 73.3 | 68.3 | 66.16 |
| 27 | 71.23 | 70.76 | 69.83 | 70.63 | 70.1 | 69.36 | 71.43 | 70.73 | 68.43 | 71.1 | 70.36 | 69.26 | 72.33 | 70.3 | 67.9 |
| 28 | 66.53 | 67.46 | 68.26 | 65.56 | 66.9 | 67.8 | 68.36 | 69.46 | 67.9 | 67.26 | 68.76 | 68.4 | 70.3 | 69.5 | 68.33 |
| 29 | 64.46 | 64.53 | 65.26 | 64.1 | 64.2 | 64.8 | 65.26 | 66.16 | 65.93 | 65. | 65.63 | 65.96 | 68.06 | 66.53 | 67.76 |
| 30 | 61.06 | 61.73 | 63.26 | 60.16 | 61.26 | 63.03 | 62.4 | 64. | 64.03 | 63.53 | 63.6 | 64.26 | 66.13 | 64.6 | 66.23 |
| 31 | 65.46 | 63.4 | 62.4 | 62.26 | 63.5 | 62.53 | 63.9 | 62.96 | 62.8 | 64.7 | 62.8 | 62.86 | 64.5 | 64.03 | 64.93 |
| Monthly average | 68.00 | 67.18 | 66.33 | 67.85 | 66.85 | 66.07 | 67.62 | 67.00 | 65.52 | 68.01 | 66.92 | 66.23 | 68.00 | 67.22 | 66.26 |

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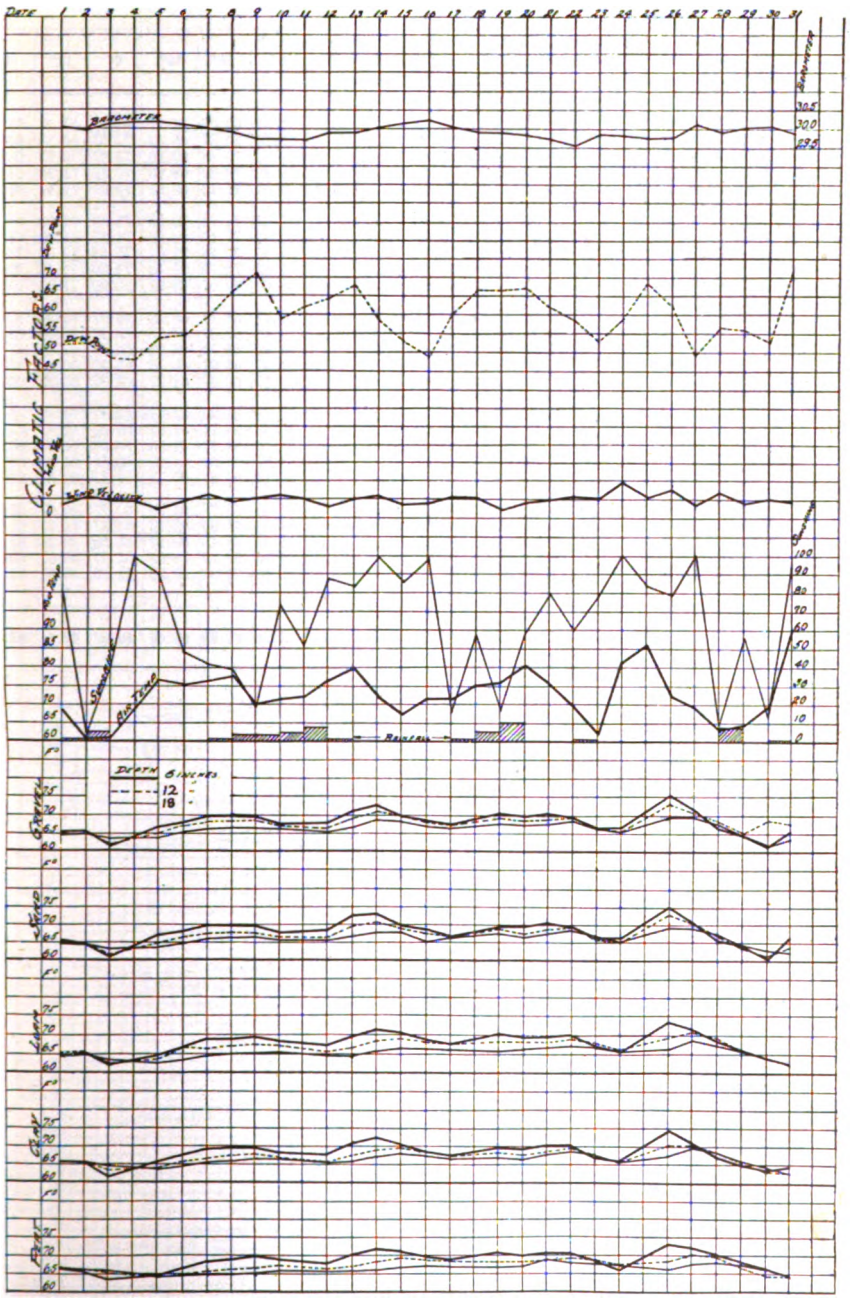


FIG 12.

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TABLE 27.—DAILY AVERAGE TEMPERATURES OF DIFFERENT TYPES OF SOIL, SEPTEMBER, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 16″ | 6″ | 12″ | 18″ |
| 2 | 74.10 | 71.63 | 68.60 | 74.40 | 71.40 | 68.33 | 72.20 | 68.73 | 65.80 | 72.83 | 69.03 | 67.13 | 71.87 | 67.57 | 65.43 |
| 3 | 73.67 | 71.90 | 69.63 | 73.70 | 71.43 | 69.10 | 72.93 | 70.17 | 67.33 | 73.20 | 70.37 | 68.53 | 73.33 | 69.13 | 66.40 |
| 4 | 72.77 | 71.67 | 70.10 | 72.63 | 71.27 | 69.63 | 73.27 | 71.20 | 68.47 | 72.33 | 70.83 | 69.50 | 73.67 | 70.73 | 68.30 |
| 5 | 73.83 | 72.23 | 70.03 | 73.57 | 71.80 | 69.90 | 73.43 | 71.30 | 69.07 | 72.80 | 70.87 | 69.63 | 73.77 | 71.10 | 68.97 |
| 6 | 73.90 | 72 20 | 70.33 | 73.93 | 71.80 | 69.83 | 73.53 | 71.43 | 69.00 | 72.63 | 71.13 | 69.87 | 74.07 | 71.47 | 69.33 |
| 7 | 74.30 | 72.43 | 70.93 | 74.40 | 72.57 | 70.43 | 74.20 | 72.03 | 69.27 | 73.27 | 71.73 | 70.20 | 75.03 | 72.00 | 69.63 |
| 9 | 74.43 | 72.73 | 70.47 | 74.23 | 72.03 | 70.10 | 73.90 | 71.60 | 69.10 | 73.87 | 71.13 | 69.80 | 74.27 | 71.70 | 69.77 |
| 10 | 75.63 | 73.93 | 71.80 | 75.03 | 73.27 | 71.40 | 75.10 | 72.93 | 70.03 | 74.20 | 72.53 | 71.07 | 75.53 | 72.87 | 70.50 |
| 11 | 73.23 | 73.03 | 72.17 | 72.33 | 72.13 | 71.50 | 74.20 | 73.27 | 70.67 | 73.63 | 72.70 | 71.43 | 74.30 | 74.43 | 70.83 |
| 12 | 66.87 | 67.40 | 68.73 | 66.37 | 66.77 | 68.23 | 68.40 | 70.23 | 69.73 | 68.00 | 69.67 | 69.97 | 70.90 | 71.93 | 70.97 |
| 13 | 67.20 | 67.00 | 67.50 | 66.67 | 66.53 | 67.23 | 67.97 | 68.60 | 68.10 | 67.47 | 68.17 | 68.30 | 69.97 | 70.30 | 70.07 |
| 14 | 66.83 | 66.73 | 66.73 | 66.23 | 66.30 | 66.60 | 67.37 | 67.73 | 66.77 | 67.40 | 67.37 | 67.33 | 68.27 | 68.73 | 68.63 |
| 16 | 64.17 | 64.40 | 65.50 | 64.07 | 64.23 | 65.23 | 65.13 | 66.17 | 65.93 | 64.87 | 65.70 | 66.03 | 66.17 | 67.40 | 67.53 |
| 17 | 62.23 | 63.10 | 64.77 | 61.63 | 62.93 | 64.77 | 63.80 | 65.40 | 65.30 | 63.30 | 64.97 | 65.53 | 65.27 | 66.97 | 67.03 |
| 18 | 61.43 | 63.53 | 64.17 | 61.37 | 62.83 | 63.57 | 63.30 | 64.00 | 64.23 | 63.37 | 63.67 | 64.27 | 63.87 | 65.30 | 66.13 |
| 19 | 59.57 | 60.87 | 62.80 | 58.97 | 60.63 | 62.77 | 61.03 | 63.27 | 63.70 | 60.23 | 62.80 | 63.67 | 62.47 | 64.63 | 65.53 |
| 20 | 59.43 | 59.57 | 61.10 | 58.97 | 59.53 | 61.23 | 59.50 | 61.30 | 62.43 | 59.33 | 60.77 | 62.07 | 60.33 | 62.87 | 64.53 |
| 21 | 61.53 | 60.83 | 61.43 | 62.07 | 61.30 | 61.37 | 60.87 | 61.23 | 61.50 | 61.10 | 61.17 | 61.63 | 60.97 | 62.00 | 63.27 |
| 23 | 59.80 | 60.00 | 61.40 | 59.20 | 59.70 | 61.37 | 60.23 | 61.40 | 62.00 | 61.37 | 61.00 | 61.90 | 60.17 | 61.90 | 63.13 |
| 24 | 59.27 | 59.10 | 60.67 | 58.70 | 59.23 | 60.37 | 59.37 | 60.47 | 60.83 | 59.13 | 60.27 | 60.73 | 59.17 | 60.57 | 61.90 |
| 25 | 61.10 | 60.57 | 61.00 | 61.23 | 60.50 | 60.93 | 61.17 | 60.73 | 60.70 | 61.80 | 60.77 | 61.00 | 60.77 | 60.67 | 61.53 |
| 26 | 60.50 | 61.40 | 62.00 | 60.47 | 61.23 | 62.10 | 61.13 | 61.83 | 61.47 | 61.30 | 61.90 | 62.10 | 61.37 | 61.53 | 61.90 |
| 27 | 55.30 | 56.43 | 59.23 | 54.10 | 55.93 | 58.97 | 56.23 | 59.70 | 60.23 | 55.80 | 59.43 | 60.37 | 56.50 | 60.23 | 61.27 |
| 28 | 53.33 | 54.97 | 57.37 | 52.63 | 54.90 | 57.70 | 54.67 | 57.43 | 59.00 | 54.20 | 57.10 | 58.67 | 55.27 | 59.07 | 60.93 |
| 30 | 51.03 | 52.13 | 54.47 | 50.63 | 51.93 | 54.90 | 51.47 | 54.43 | 56.23 | 51.40 | 54.00 | 55.83 | 51.90 | 55.67 | 58.57 |
| Monthly average | 65.48 | 65.20 | 65.33 | 65.08 | 64.88 | 65.08 | 65.76 | 65.82 | 65.08 | 65.58 | 65.58 | 65.48 | 66.37 | 66.44 | 66.66 |

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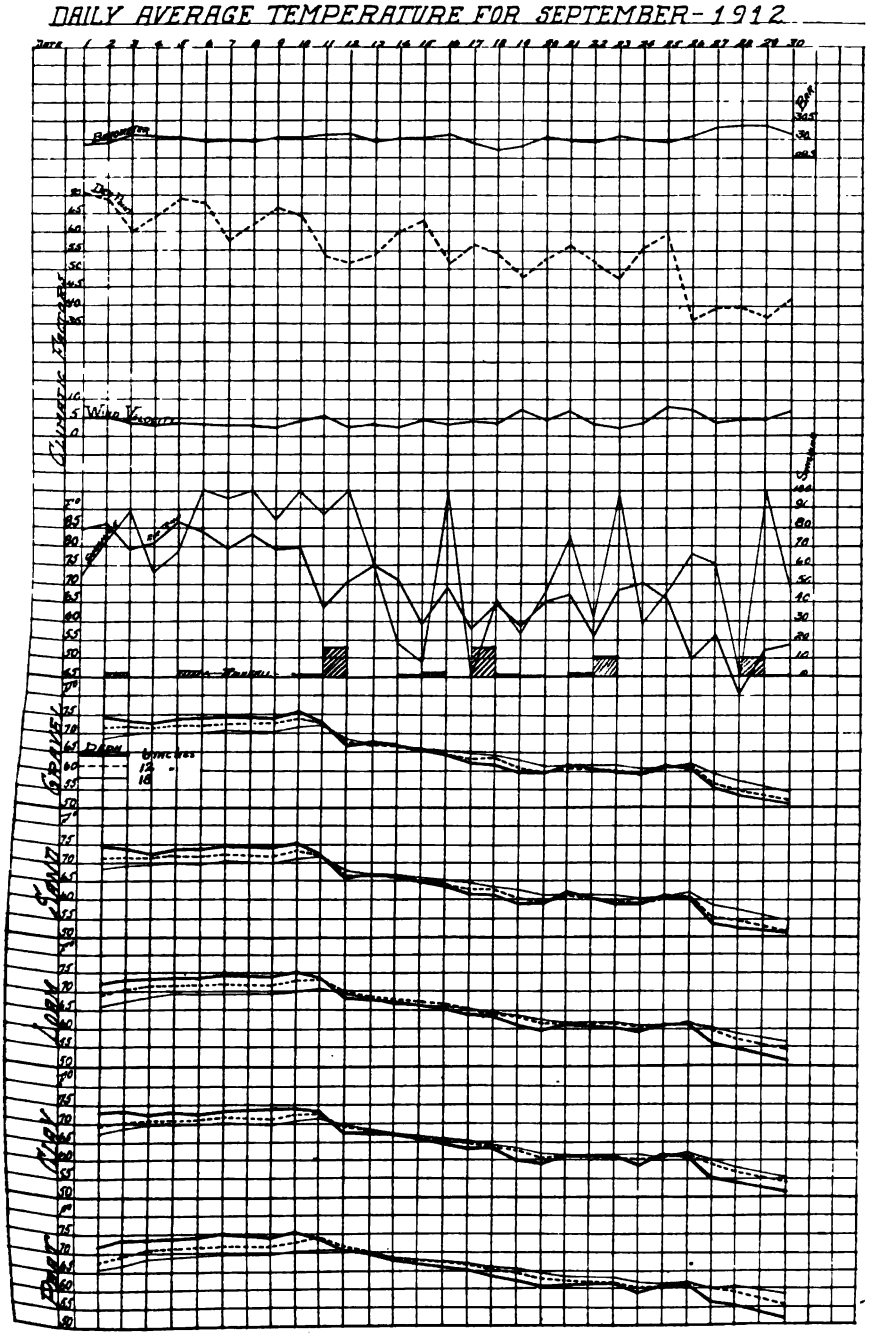


FIG. 13.

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TABLE 27.—DAILY AVERAGE TEMPERATURES OF DIFFERENT TYPES OF SOIL, SEPTEMBER, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 16″ | 6″ | 12″ | 18″ |
| 2 | 74.10 | 71.63 | 68.60 | 74.40 | 71.40 | 68.33 | 72.20 | 68.73 | 65.80 | 72.83 | 69.03 | 67.13 | 71.87 | 67.57 | 65.43 |
| 3 | 73.67 | 71.90 | 69.63 | 73.70 | 71.43 | 69.10 | 72.93 | 70.17 | 67.33 | 73.20 | 70.37 | 68.53 | 73.33 | 69.13 | 66.40 |
| 4 | 72.77 | 71.67 | 70.10 | 72.63 | 71.27 | 69.63 | 73.27 | 71.20 | 68.47 | 72.33 | 70.83 | 69.50 | 73.67 | 70.73 | 68.30 |
| 5 | 73.83 | 72.23 | 70.03 | 73.57 | 71.80 | 69.90 | 73.43 | 71.30 | 69.07 | 72.80 | 70.87 | 69.63 | 73.77 | 71.10 | 68.97 |
| 6 | 73.90 | 72 20 | 70.33 | 73.93 | 71.80 | 69.83 | 73.53 | 71.43 | 69.00 | 72.63 | 71.13 | 69.87 | 74.07 | 71.47 | 69.33 |
| 7 | 74.30 | 72.43 | 70.93 | 74.40 | 72.57 | 70.43 | 74.20 | 72.03 | 69.27 | 73.27 | 71.73 | 70.20 | 75.03 | 72.00 | 69.63 |
| 9 | 74.43 | 72.73 | 70.47 | 74.23 | 72.03 | 70.10 | 73.90 | 71.60 | 69.10 | 73.87 | 71.13 | 69.80 | 74.27 | 71.70 | 69.77 |
| 10 | 75.63 | 73.93 | 71.80 | 75.03 | 73.27 | 71.40 | 75.10 | 72.93 | 70.03 | 74.20 | 72.53 | 71.07 | 75.53 | 72.87 | 70.50 |
| 11 | 73.23 | 73.03 | 72.17 | 72.33 | 72.13 | 71.50 | 74.20 | 73.27 | 70.67 | 73.63 | 72.70 | 71.43 | 74.30 | 74.43 | 70.83 |
| 12 | 66.87 | 67.40 | 68.73 | 66.37 | 66.77 | 68.23 | 68.40 | 70.23 | 69.73 | 68.00 | 69.67 | 69.97 | 70.90 | 71.93 | 70.97 |
| 13 | 67.20 | 67.00 | 67.50 | 66.67 | 66.53 | 67.23 | 67.97 | 68.60 | 68.10 | 67.47 | 68.17 | 68.30 | 69.97 | 70.30 | 70.07 |
| 14 | 66.83 | 66.73 | 66.73 | 66.23 | 66.30 | 66.60 | 67.37 | 67.73 | 66.77 | 67.40 | 67.37 | 67.33 | 68.27 | 68.73 | 68.63 |
| 16 | 64.17 | 64.40 | 65.50 | 64.07 | 64.23 | 65.23 | 65.13 | 66.17 | 65.93 | 64.87 | 65.70 | 66.03 | 66.17 | 67.40 | 67.53 |
| 17 | 62.23 | 63.10 | 64.77 | 61.63 | 62.93 | 64.77 | 63.80 | 65.40 | 65.30 | 63.30 | 64.97 | 65.53 | 65.27 | 66.97 | 67.03 |
| 18 | 61.43 | 63.53 | 64.17 | 61.37 | 62.83 | 63.57 | 63.30 | 64.00 | 64.23 | 63.37 | 63.67 | 64.27 | 63.87 | 65.30 | 66.13 |
| 19 | 59.57 | 60.87 | 62.80 | 58.97 | 60.63 | 62.77 | 61.03 | 63.27 | 63.70 | 60.23 | 62.80 | 63.67 | 62.47 | 64.63 | 65.53 |
| 20 | 59.43 | 59.57 | 61.10 | 58.97 | 59.53 | 61.23 | 59.50 | 61.30 | 62.43 | 59.33 | 60.77 | 62.07 | 60.33 | 62.87 | 64.53 |
| 21 | 61.53 | 60.83 | 61.43 | 62.07 | 61.30 | 61.37 | 60.87 | 61.23 | 61.50 | 61.10 | 61.17 | 61.63 | 60.97 | 62.00 | 63.27 |
| 23 | 59.80 | 60.00 | 61.40 | 59.20 | 59.70 | 61.37 | 60.23 | 61.40 | 62.00 | 61.37 | 61.00 | 61.90 | 60.17 | 61.90 | 63.13 |
| 24 | 59.27 | 59.10 | 60.67 | 58.70 | 59.23 | 60.37 | 59.37 | 60.47 | 60.83 | 59.13 | 60.27 | 60.73 | 59.17 | 60.57 | 61.90 |
| 25 | 61.10 | 60.57 | 61.00 | 61.23 | 60.50 | 60.93 | 61.17 | 60.73 | 60.70 | 61.80 | 60.77 | 61.00 | 60.77 | 60.67 | 61.53 |
| 26 | 60.50 | 61.40 | 62.00 | 60.47 | 61.23 | 62.10 | 61.13 | 61.83 | 61.47 | 61.30 | 61.90 | 62.10 | 61.37 | 61.53 | 61.90 |
| 27 | 55.30 | 56.43 | 59.23 | 54.10 | 55.93 | 58.97 | 56.23 | 59.70 | 60.23 | 55.80 | 59.43 | 60.37 | 56.50 | 60.23 | 61.27 |
| 28 | 53.33 | 54.97 | 57.37 | 52.63 | 54.90 | 57.70 | 54.67 | 57.43 | 59.00 | 54.20 | 57.10 | 58.67 | 55.27 | 59.07 | 60.93 |
| 30 | 51.03 | 52.13 | 54.47 | 50.63 | 51.93 | 54.90 | 51.47 | 54.43 | 56.23 | 51.40 | 54.00 | 55.83 | 51.90 | 55.67 | 58.57 |
| Monthly average | 65.40 | 65.20 | 65.33 | 65.08 | 64.88 | 65.08 | 65.76 | 65.82 | 65.08 | 65.56 | 65.56 | 65.46 | 66.37 | 66.44 | 66.06 |

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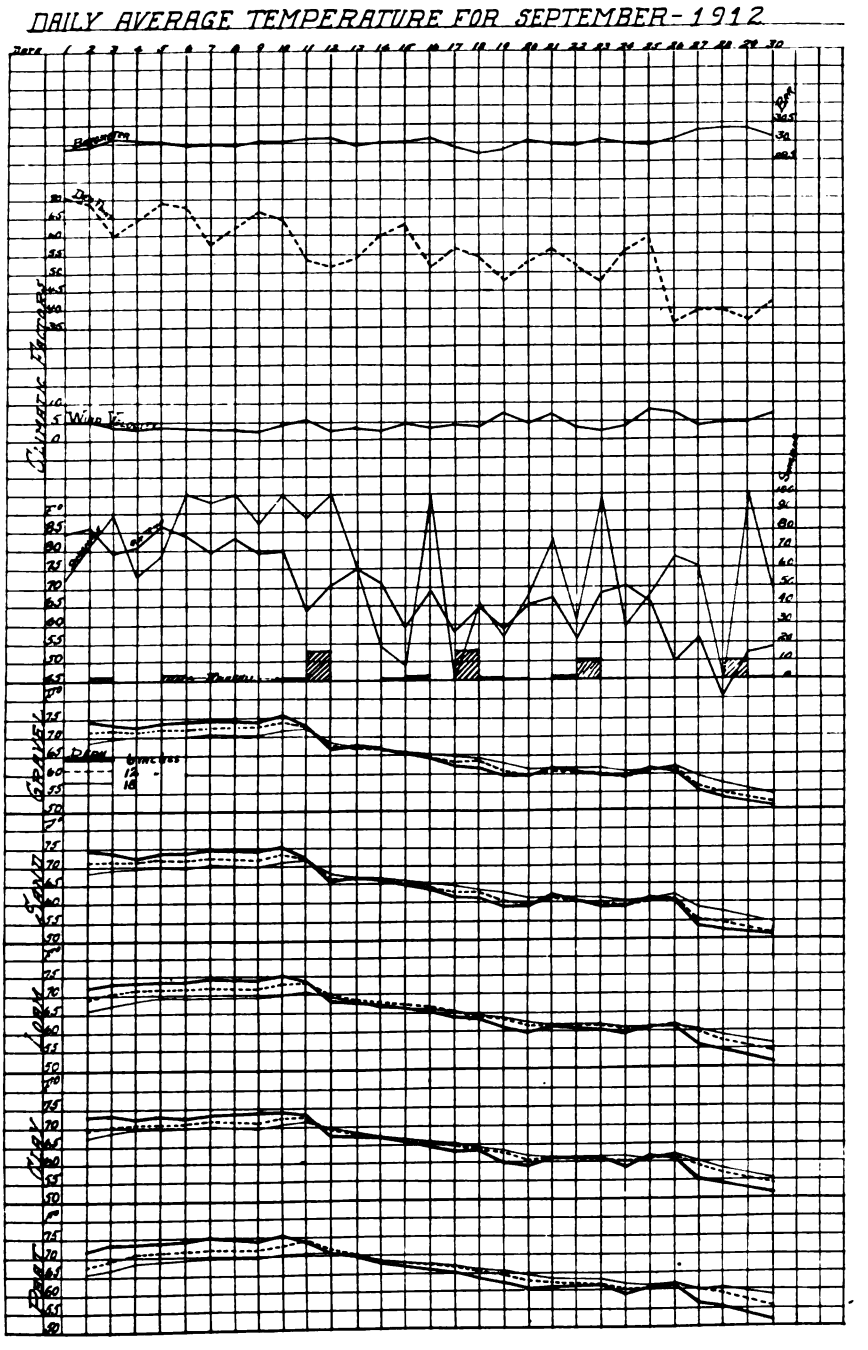


FIG. 13.

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TABLE 28.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, OCTOBER, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 53.50 | 52.90 | 54.53 | 52.20 | 53.00 | 51.53 | 55.63 | 53.93 | 55.36 | 52.60 | 53.66 | 55.33 | 51.83 | 54.80 | 56.17 |
| 2 | 53.53 | 53.53 | 54.96 | 53.53 | 53.46 | 55.16 | 52.73 | 54.90 | 55.23 | 53.20 | 54.40 | 53.36 | 52.03 | 54.46 | 57.33 |
| 3 | 53.20 | 54.20 | 55.00 | 52.46 | 54.26 | 55.40 | 53.20 | 57.60 | 55.10 | 53.16 | 54.60 | 55.56 | 52.73 | 54.30 | 56.43 |
| 5 | 56.03 | 59.06 | 56.03 | 56.33 | 55.86 | 55.03 | 54.76 | 55.00 | 55.26 | 55.46 | 55.40 | 54.89 | 54.36 | 54.70 | 55.63 |
| 7 | 59.03 | 58.83 | 58.20 | 59.03 | 58.73 | 58.26 | 58.60 | 57.56 | 56.63 | 59.00 | 57.96 | 57.33 | 57.73 | 55.63 | 56.36 |
| 8 | 52.90 | 54.83 | 57.13 | 52.03 | 54.06 | 56.43 | 54.10 | 57.13 | 57.03 | 53.90 | 56.50 | 57.70 | 54.70 | 56.36 | 56.93 |
| 9 | 51.56 | 52.23 | 53.30 | 51.26 | 52.06 | 54.03 | 52.03 | 54.23 | 55.33 | 52.36 | 53.90 | 54.50 | 52.30 | 54.86 | 56.36 |
| 10 | 53.76 | 54.13 | 54.93 | 53.63 | 54.13 | 55.10 | 53.83 | 54.76 | 55.10 | 53.76 | 54.56 | 55.16 | 53.76 | 54.76 | 56.36 |
| 11 | 55.80 | 54.96 | 54.93 | 55.40 | 55.10 | 55.16 | 54.56 | 54.70 | 54.96 | 55.20 | 54.66 | 54.93 | 54.16 | 54.66 | 56.06 |
| 12 | 56.06 | 56.26 | 56.26 | 55.66 | 56.26 | 56.56 | 56.30 | 55.76 | 55.56 | 56.33 | 56.40 | 56.20 | 56.23 | 55.36 | 56.43 |
| 15 | 49.16 | 49.90 | 51.93 | 49.26 | 50.20 | 52.73 | 49.36 | 51.60 | 53.10 | 49.80 | 51.40 | 52.90 | 49.56 | 52.76 | 55.00 |
| 16 | 46.83 | 48.00 | 50.43 | 46.93 | 48.40 | 50.97 | 47.07 | 49.90 | 51.67 | 47.27 | 49.67 | 51.50 | 47.43 | 50.73 | 54.00 |
| 17 | 48.60 | 48.90 | 50.47 | 48.57 | 49.03 | 51.00 | 48.00 | 49.93 | 51.33 | 48.20 | 49.50 | 51.13 | 47.37 | 50.23 | 53.23 |
| 18 | 52.27 | 51.60 | 52.03 | 52.63 | 52.03 | 52.13 | 50.63 | 51.00 | 51.63 | 51.67 | 50.70 | 51.57 | 49.50 | 50.20 | 52.93 |
| 19 | 50.20 | 50.93 | 51.30 | 49.87 | 51.97 | 51.80 | 51.50 | 51.17 | 52.03 | 50.97 | 52.03 | 52.43 | 51.03 | 50.47 | 52.60 |
| 21 | 49.47 | 49.57 | 50.70 | 49.33 | 49.70 | 51.30 | 50.50 | 49.03 | 51.77 | 49.57 | 50.30 | 51.60 | 48.83 | 50.93 | 53.30 |
| 22 | 52.30 | 52.87 | 52.73 | 53.83 | 53.00 | 52.77 | 51.50 | 52.57 | 51.97 | 52.53 | 51.77 | 51.87 | 51.40 | 50.37 | 52.37 |
| 23 | 47.10 | 49.13 | 51.27 | 46.80 | 49.17 | 50.90 | 49.97 | 49.50 | 51.53 | 48.30 | 50.83 | 51.47 | 49.53 | 50.00 | 51.67 |
| 24 | 44.70 | 46.30 | 49.60 | 44.20 | 46.37 | 49.80 | 48.70 | 46.37 | 51.60 | 45.23 | 48.93 | 50.83 | 47.83 | 50.63 | 52.10 |
| 25 | 44.30 | 45.57 | 48.13 | 44.37 | 45.43 | 48.47 | 47.13 | 45.23 | 50.00 | 44.50 | 47.80 | 49.40 | 45.87 | 49.80 | 52.03 |
| 26 | 45.33 | 45.97 | 48.07 | 45.40 | 46.33 | 48.80 | 44.97 | 47.40 | 49.33 | 45.37 | 47 30 | 48.87 | 45.30 | 48.53 | 51.30 |
| 28 | 46.93 | 46.96 | 48.20 | 46.83 | 47.30 | 48.63 | 45.73 | 47.07 | 48.67 | 46.30 | 47.20 | 48.40 | 45.57 | 47.10 | 49.87 |
| 29 | 48.86 | 48.76 | 49.33 | 48.96 | 48.93 | 49.66 | 47.50 | 48.30 | 48.96 | 48.23 | 48.43 | 49.03 | 46.66 | 47.40 | 49.73 |
| 30 | 45.80 | 47.16 | 49.16 | 45.33 | 47.73 | 49.26 | 46.30 | 48.43 | 49.16 | 46.33 | 48.43 | 49.10 | 46.80 | 47.76 | 49.73 |
| 31 | 41.56 | 43.66 | 47.13 | 40.66 | 43.46 | 47.80 | 42.80 | 46.76 | 48.83 | 42.63 | 46.70 | 48.46 | 44.40 | 47.43 | 49.40 |
| Monthly average | 50.38 | 51.05 | 52.25 | 50.16 | 51.05 | 52.37 | 50.68 | 51.48 | 52.60 | 50.48 | 51.48 | 52.61 | 50.28 | 51.77 | 53.88 |

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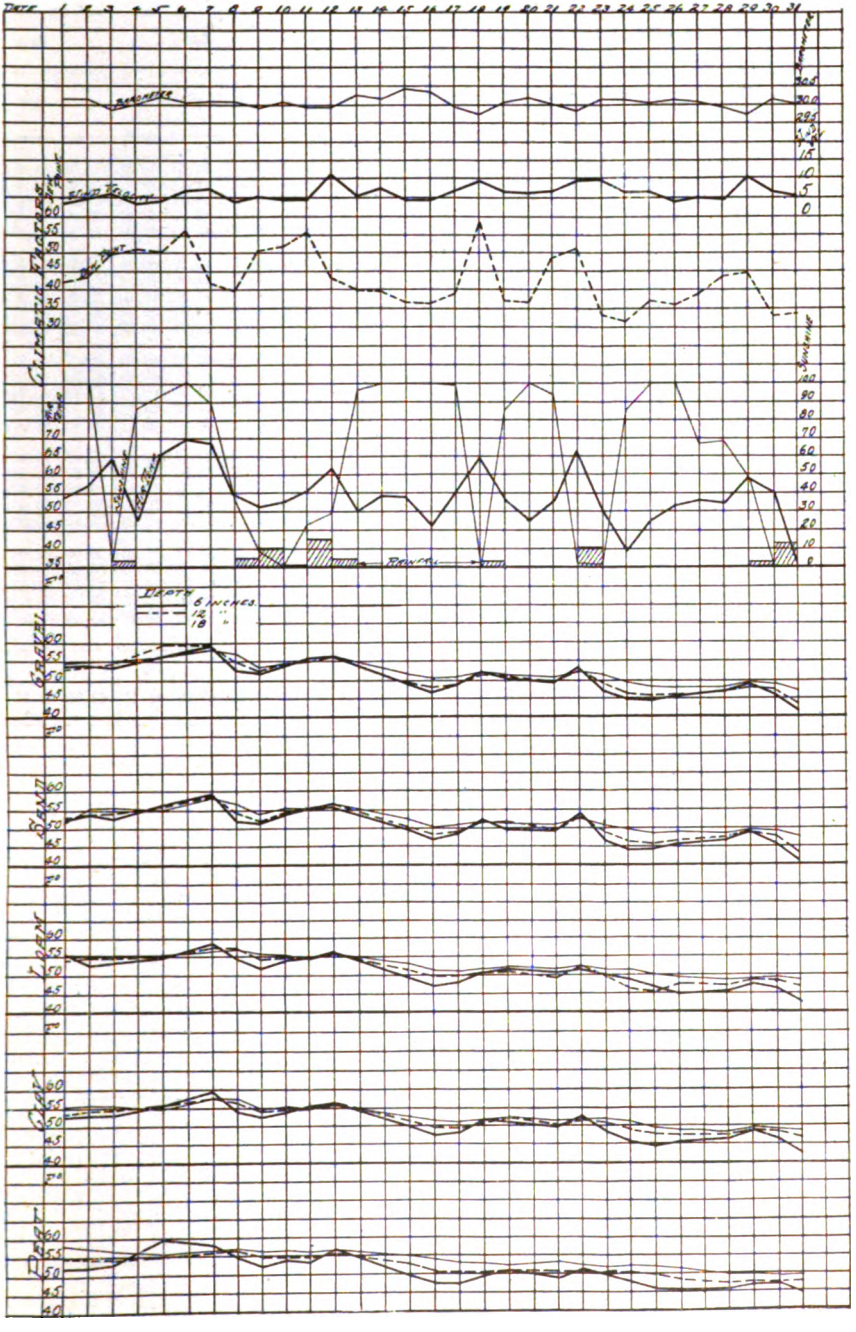


FIG. 14.

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TABLE 29.—DAILY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOVEMBER, 1912.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 38.30 | 41.06 | 44.86 | 37.90 | 41.30 | 45.43 | 40.10 | 44.50 | 47.43 | 39.60 | 44.23 | 46.56 | 41.90 | 46.46 | 49.33 |
| 2 | 36.87 | 38.97 | 43.03 | 36.17 | 38.97 | 43.33 | 37.90 | 42.43 | 45.73 | 35.77 | 42.17 | 44.73 | 39.40 | 44.43 | 48.47 |
| 4 | 37.97 | 39.10 | 42.03 | 37.53 | 39.30 | 42.67 | 37.63 | 40.90 | 43.90 | 38.00 | 40.87 | 43.00 | 37.20 | 41.67 | 45.67 |
| 5 | 42.10 | 42.17 | 43.30 | 42.37 | 42.60 | 43.87 | 40.70 | 41.87 | 43.80 | 41.27 | 42.00 | 43.40 | 38.63 | 41.10 | 44.97 |
| 6 | 47.27 | 46.67 | 46.10 | 47.50 | 47.27 | 46.27 | 45.47 | 44.53 | 44.83 | 46.33 | 45.03 | 45.07 | 42.97 | 41.87 | 44.53 |
| 7 | 45.50 | 46.17 | 47.00 | 45.30 | 46.23 | 47.13 | 45.27 | 46.00 | 45.97 | 45.77 | 46.27 | 46.60 | 44.37 | 43.53 | 44.87 |
| 8 | 42.60 | 43.53 | 45.73 | 42.43 | 43.43 | 45.77 | 42.70 | 44.83 | 46.27 | 42.70 | 44.90 | 46.13 | 42.43 | 43.90 | 45.13 |
| 9 | 42.00 | 43.03 | 45.13 | 42.03 | 43.37 | 45.60 | 42.10 | 44.37 | 46.10 | 42.23 | 44.33 | 45.70 | 42.10 | 43.97 | 45.97 |
| 11 | 45.17 | 44.73 | 45.10 | 45.30 | 44.83 | 45.47 | 43.67 | 44.13 | 45.27 | 44.17 | 44.07 | 45.13 | 42.27 | 43.17 | 45.50 |
| 12 | 49.50 | 48.73 | 47.27 | 49.73 | 48.77 | 47.33 | 47.87 | 46.53 | 46.10 | 48.03 | 46.77 | 46.37 | 45.83 | 44.17 | 45.70 |
| 13 | 50.50 | 50.40 | 49.43 | 50.30 | 50.20 | 49.40 | 50.10 | 49.07 | 47.83 | 50.57 | 49.30 | 48.53 | 48.57 | 46.17 | 46.43 |
| 14 | 41.53 | 44.10 | 47.60 | 40.80 | 43.93 | 47.50 | 43.73 | 47.30 | 48.30 | 43.77 | 47.07 | 48.27 | 45.33 | 46.90 | 46.50 |
| 15 | 37.97 | 40.43 | 44.53 | 37.57 | 40.67 | 44.90 | 39.53 | 44.13 | 46.90 | 39.03 | 43.60 | 45.90 | 41.93 | 45.90 | 47.90 |
| 16 | 35.90 | 38.33 | 42.70 | 35.57 | 38.70 | 43.17 | 37.23 | 41.83 | 44.80 | 36.87 | 41.30 | 43.70 | 39.27 | 43.80 | 46.93 |
| 18 | 37.93 | 39.07 | 41.87 | 37.37 | 39.13 | 42.27 | 37.47 | 40.30 | 42.90 | 37.80 | 40.27 | 42.27 | 37.63 | 41.07 | 44.33 |
| 19 | 38.83 | 39.67 | 41.93 | 38.63 | 39.77 | 42.23 | 38.07 | 40.37 | 42.77 | 38.53 | 40.47 | 42.13 | 37.70 | 40.33 | 43.93 |
| 20 | 39.03 | 39.37 | 42.13 | 38.70 | 39.37 | 42.40 | 38.27 | 40.87 | 42.43 | 38.47 | 41.03 | 42.37 | 38.20 | 40.40 | 43.43 |
| 21 | 41.27 | 41.37 | 42.30 | 41.43 | 41.67 | 42.63 | 40.33 | 41.00 | 42.27 | 40.60 | 41.37 | 42.07 | 39.03 | 39.67 | 42.50 |
| 22 | 38.27 | 39.67 | 42.37 | 38.03 | 40.10 | 42.73 | 38.80 | 41.53 | 42.90 | 38.60 | 41.57 | 42.73 | 39.10 | 40.50 | 42.77 |
| 23 | 36.90 | 38.55 | 41.60 | 36.75 | 38.85 | 41.95 | 37.55 | 40.60 | 42.50 | 37.35 | 40.50 | 42.20 | 38.10 | 40.50 | 42.95 |
| 25 | 35.83 | 37.37 | 40.17 | 35.40 | 37.60 | 40.77 | 35.97 | 39.00 | 41.70 | 36.07 | 38.97 | 41.03 | 36.67 | 39.73 | 42.77 |
| 26 | 34.73 | 36.30 | 39.10 | 34.23 | 36.50 | 39.73 | 34.97 | 38.00 | 40.60 | 35.00 | 37.90 | 39.90 | 35.63 | 38.60 | 41.93 |
| 27 | 34.87 | 36.30 | 38.97 | 34.57 | 36.40 | 39.43 | 34.87 | 37.83 | 40.30 | 34.90 | 37.73 | 39.60 | 35.47 | 38.40 | 41.63 |
| 29 | 35.45 | 36.70 | 39.40 | 35.00 | 37.50 | 39.90 | 35.35 | 38.15 | 41.30 | 35.45 | 38.00 | 39.85 | 35.85 | 38.55 | 41.80 |
| 30 | 34.87 | 36.30 | 38.73 | 34.50 | 36.43 | 39.40 | 34.80 | 35.70 | 40.10 | 35.00 | 37.70 | 39.27 | 35.20 | 37.87 | 41.13 |
| Monthly average | 40.44 | 41.13 | 43.32 | 39.00 | 41.32 | 43.67 | 40.00 | 42.28 | 44.12 | 40.00 | 42.29 | 43.70 | 40.00 | 42.11 | 44.68 |

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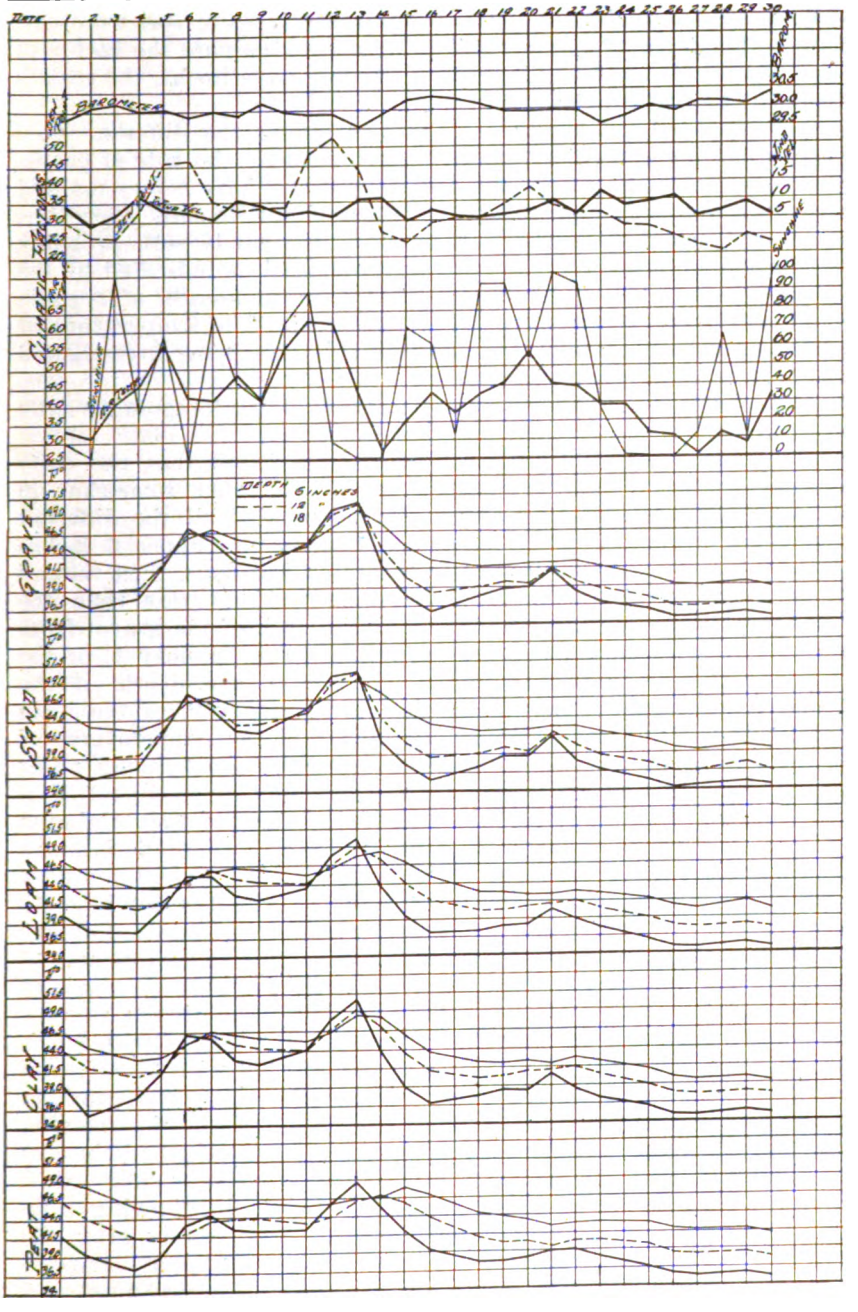


FIG. 15.

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Before entering into the discussion of the foregoing results, the reader should be reminded again that all these different types of soil were covered with a thin layer of a sandy soil in order to eliminate the factor of color as this factor was investigated in a separate experiment, the results of which will be presented subsequently.

The thin layer of the sandy soil, besides giving the different soils about the same shade of color, tended also to equalize the rate of evaporation of their moisture. Both color and evaporation have a very marked influence upon the soil temperature. If these different soils, therefore, had not been covered with the thin layer of the sandy soil, probably somewhat different results might have been obtained as indicated by the data of the experiment on the effect of different amounts of organic matter on soil temperature—later to be presented. The temperature of these different soil types, however, uncovered, is now being investigated and the data will be reported later.

With these facts in mind a detailed discussion of the foregoing results is now in order.

Beginning with the middle of November it is found that the daily average temperature of the different types of soil runs somewhat in this manner: The temperature at all three depths of all the different soils decreased gradually until December 1 when the upper 6 inches of every soil froze. They all stayed frozen for a few days, then thawed and froze again the latter part of December. About this time the lower depths also began to freeze. The 12-inch depth of the gravel froze December 29, of the sand December 30, of the loam January 1, of the clay January 2, of the peat January 2. The 18-inch depth of the gravel and sand froze January 3, of the clay January 9, of the loam January 12, and of the peat January 20. None of the temperatures of any of the depths of any of the soils remained at the freezing point but continued to fall rapidly until a minimum was reached and then began to rise again. At the depth of 6 inches the average minimum was reached for gravel January 6 with 19.96° F., for sand January 6 with 14.73°, for loam January 8 with 21.86°, for clay January 8 with 21.7°, and for peat January 8 with 19.63°. At the depth of 12 inches the lowest average temperature was reached for gravel January 8 with 23.96°, for sand January 8 with 23.00°, for loam January 15 with 28.6°, for clay January 17 with 27.13°, and for peat January 13 with 27.8°. At the depth of 18 inches, the average minimum was attained for gravel January 13 with 29.7°, for sand January 17 with 30.1°, for loam January 20 with 30.5°, for clay January 22 with 29.83°, and for peat January 30 with 30.76°. The rising in every case was gradual, varying slightly from day to day and tending to attain the freezing point, but was below this throughout the cold period. Up to February 19 the temperature of the upper 6 inches fluctuated near 28.0°, then rose to about 30.0° and remained near that point till thawing commenced. The temperature of the 12-inch depth rose shortly after the minimum was attained to about 29.0° and stayed near that temperature until about the middle of February, then rose to about 30.0° F. and remained at about that point also till thawing took place. The temperature of the 18-inch depth of all the soils ranged near 30.0° to 31.0° F. from the time the lowest temperature took place till the thawing

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period. The thawing commenced about the beginning of April. The various soils and the different depths within the same soil thawed at different dates. The 6-inch depth of the gravel and sand thawed April 5, of the clay April 6, of the loam April 7 and of the peat April 15. The 12-inch of the gravel thawed April 5, of the sand April 6, of the clay April 10, of the loam April 13 and of the peat May 1. The 18-inch depth of the gravel and sand thawed April 7, of the clay April 12, of the loam April 15, and of the peat April 24.

Immediately after the commencement of thawing, the temperature of the different soils at the 6-inch depth began to rise quite rapidly but at different rates. The temperature of both the gravel and sand rose far above that of the other soils, followed by clay, loam, and peat respectively. This order of magnitude continued until all the lower depths of the heavier soils thawed, then their temperature rose rapidly and approached that of the lighter soils. The time that it took the heavier soils to attain the same temperature as the lighter soils at the 6-inch depth varied with the soil, for the clay it was 11 days (April 16), for the loam 12 days (April 17), and for the peat 32 days (May 6), from the date the upper 6 inches of the gravel and sand began to thaw. From these dates on, the temperature of the upper surface of all the soils ran about the same.

The temperature of all the soils at all three depths continued to rise till July when the maximum temperature was attained, and then began to fall. At the depth of 6 inches the highest average temperature for all soils was reached on July 11 with the following magnitude: gravel 79.26°, sand 77.4°, loam 78.86°, clay 76.73°, peat 79.33°. At the depth of 12 inches the highest average temperature was attained for gravel on July 11 with 76.8°, for sand July 10 with 75.16°, for loam July 12 with 75.26°, for clay July 11 with 74.73°, and for peat July 12 with 75.73°. While at the depth of 18 inches the highest average temperature is shown by gravel and sand on July 12 with 73.36° and 72.2°, respectively, by loam July 13 with 71.63°, by clay July 13 with 72.5°, and by peat July 13 with 72.23°. From these dates on, the temperature of all the soils at all three depths fell irregularly but gradually till freezing.

The data for the second year, or cycle, are not presented here but they are on file and show that as far as they go they confirm the first year's results perfectly. The first freezing, for instance, occurred about the middle of December, and as in the previous year the upper 6 inches of all the soils froze about the same time as shown by the following dates: Gravel and sand Dec. 12, loam and clay Dec. 13, and peat Dec. 14. All these soils remained frozen at this depth until Dec. 18th when they all thawed and froze again Dec. 23. The 12-inch depth of the gravel and sand froze Feb. 3, of the clay and loam Feb. 5, and of the peat Feb. 6, while the 18-inch depth of the gravel froze Feb. 6, of the sand Feb. 8, of the loam Feb. 11, of the clay Feb. 10 and of the peat Feb. 23. The lowest average temperature that all the different soils reached at the upper 6-inch depth was on Feb. 13, with the following results: Gravel 22.43° F., sand 19.60°, loam 23.30°, clay 23.93°, and peat 20.50°. In the spring all these soils thawed in the same order as in the first spring.

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Thus far the daily march of average temperature for the five different kinds of soils has been given without any comment or explanation of the results. It will not be well to discuss the foregoing data in a brief manner and emphasize the most important and essential facts. After this the consideration of the meteorological elements and their influence upon the foregoing results will be in order.

One of the most important facts that needs emphasis is the rate at which all the different types of soil cooled and froze at the upper 6-inch depth. It is a common belief, and a logical one, that the lightest soils cool the fastest and the heaviest soils the slowest, and warm up in the some order. The preceding data, however, show very conclusively that the gravel and sand at the upper 6-inch depth cooled and froze about the same time as the clay, loam and peat.

In the spring the two light soils thawed at the upper depth first and both at the same time, followed by clay, one day later, loam two days later, and peat ten days later, and that the temperature of the light soils rose and remained far above that of the heavy soils, for some time.

The question now is why should there be this anomaly or disagreement. The explanation may be found, as will be subsequently given, in the difference in the moisture content of the various soils and in the fluctuating downward and upward trend of the air temperature in the fall and spring respectively.

As previously stated, the moisture content of these soils was determined at various times of the year. In table 4 are given the determinations of April 3 just before thawing commenced and in November 4 when the rapid cooling began. It is seen that the percentage of the water content varies tremendously among the various soils which in turn affects their specific heat very greatly. As shown in that table (4) 100 heat units or calories will raise the temperature of the soils in the dry condition as follows: gravel, .00895° C. sand .01117°, loam .01401°, clay .01399°, peat .02374°. When the moisture content is also considered then the raise is as follows: gravel .006520° C., sand .005876°, loam .004848°, clay .005690°, peat .002127°. These latter figures show that the temperature of the sand or gravel rises two or three times higher than that of the peat with the same number of heat units. From this we should expect that in the spring the light soils should warm much earlier than the peat soils, and in the fall they should cool in the same order. The foregoing data show that in the spring they do warm up in the order given or in the order of their specific heats, but in the fall they cool almost at the same rate and freeze about the same time.

The difference in the moisture content together with the upward and downward trend of temperature in the spring and fall respectively, account for this disagreement. In the spring the daily march of the air temperature has a continually upward trend. The lighter soils having the lowest specific heat warm up early and their temperature fluctuates as the weather elements vary, but the trend is upward. The heavier soils and especially the peat having the greatest heat capacity warm up slowly but gradually and finally reach the same temperature as the lighter soils. In the fall the trend of the air temperature is downward as is also that of the soils. On certain days the air temperature falls very low, whereupon all the soils are cooled, the light soils the most

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and the heavy soils the least; next day the air temperature rises considerably and the temperature of the soils rises according to their specific heat: the light soils attain the highest temperature as in the spring, and the heavier soils the lowest; another day follows with very low temperature whereupon all the soils lose heat again in the same order as above: the sand and gravel as usual lose more than the other soils, but they attained a higher temperature during the day time and consequently have more apparent heat to lose. These alternate cold and warm days with the downward trend of air temperature tend to keep the lighter soils as warm as the heavier soils.

If the air temperature would continue to drop very rapidly without any warm days intervening, then the light soils would cool or freeze most rapidly and would continue to have a much lower temperature. This is well illustrated whenever a severe cold weather sets in as on January 8, 1911, when the coldest day of the year occurred and the soil temperature dropped very low. On this date the light soils cooled the most and the heavy soils the least. It is in such occasions or circumstances as these that high moisture content becomes an advantage and renders highly practical benefits.

The next most interesting fact that the foregoing tables and charts show is the same magnitude of temperature in the upper 6 inches of all the different types of soil at all times except during thawing. Here again it is the common belief that the light soils, for the same reason that they warm up the fastest in the spring and cool most rapidly in the fall, have the highest temperature during the summer months and lowest during the winter months. The data, as already stated, show most decidedly that the average temperatures of all the soils in the upper 6-inch layer are practically the same, varying, as a monthly average, only about 1° F. from May through summer and fall till freezing time, and this slight variation being in favor of the peat during July, August, and September. The variation is greater than 1° on certain individual days but this is largely due to rapid changes in the air temperature and to some other temporary factors. The 12 and 18-inch depths of all the soils have also practically the same temperature throughout the year except during thawing.

Theoretically, that is what should be expected if heat conductivity had no very marked influence, and if all the other conditions, evaporation, color and radiation, were about equal. The color was eliminated by covering all the soils by the same kind of soil; there was probably not a very great difference in evaporation. If these two factors were about equal for all soils then they all received about the same amount of warmth during the sun insolation. Their temperature, however, rose to different degrees on account of their different specific heats. The light soils having the smallest heat capacity under the field conditions attained the highest temperature during the day and the heavier soils the lowest. During the night they all cooled and since the previous study on radiation shows that all soils in well-moistened condition radiate equally well and since all these soils were covered with the same kind of soil and since it is conceived that radiation takes place at the surface, then all the soils lost about the same amount of heat, but received different degrees of lowering of temperature on account of



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their different specific heats: the light soils with the smallest heat capacity cooled the most and the heavier soils with the largest capacity for heat the least. The average between the maximum and minimum temperature ought to give the same temperature for all the soils. That is just what has been obtained.

The temperature of the peat during the summer months is very interesting and deserves special attention. This material has not only the greatest water holding capacity of any other soil, but also the ability to absorb considerable moisture from the air, and on account of the slow but continuous evaporation of the water the temperature of this soil is kept low or much lower than that of other soils, as will be shown in a subsequent experiment, but when it is covered with a thin layer sand, as was done in the present experiment, its temperature is higher that that of the other different types of soil. A thin top dressing of sand, therefore, appears to increase the temperature of peat soils. This seems to be true also with the other heavy soils.

It would seem, then, from this study, that the greatest difference in temperature between the different types of soil exists in the early spring during thawing and immediately afterwards. Perhaps this is the most important period of the year from the practical or agricultural point of view, and especially where planting in the spring has to be done very early, because at this season small differences in the temperature will make great differences in the rate of germination of seed and in the rate of growth of plants. The differences in the present case are quite appreciable. As has already been mentioned, the gravelly and sandy soils not only thawed first followed by clay 1 day later, loam 2 days later, and peat 10 days later, but the temperature of the former soils rose immediately about 10° or more above that of the other soils. It took the clay soil 11 days to attain the same temperature as the light soils, the loam 12 days and the peat 32 days. Since this difference in the rate of thawing and rising of temperature in the various soil types is largely due to their different water content, and hence to the specific heat of water, the conclusion is irresistable that water is the most predominal controlling agent of soil temperature at this period and is of disadvantage. This disadvantage, however, becomes an advantage during the rapid fall of the air temperature in the cold parts of the year.

Special attention might also be called to the thawing of the 18-inch depth of peat 7 days before the 12-inch. This is interesting because it tends to confirm the general theory that the soil receives in the winter some heat from the interior of the earth.

### EFFECT OF THE METEOROLOGICAL ELEMENTS ON THE SOIL TEMPERATURE.

So far the temperature of the different types of soil has been considered as affected or controlled by the difference of their intrinsic or soil factors. It will now be well to consider the temperature of these soils in relation to the external or meteorological elements which are air temperature, sunshine, wind pressure, precipitation, dew point, cloudiness, etc. These meteorological elements are very complex as to their behavior and make it very difficult to see the influence of all of

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them on the soil temperature. In the first place, some of them run in a direct or parallel course with each other, while others run in an inverse course. This opposing or contrary action makes it very hard to notice or correlate the influence of any element on soil temperature unless it is very predominant. In the second place, all these elements do not obey the same law from day to day and hence this makes it still more difficult to trace their influence on the soil temperature.

As a rule, however, they tend to act with one another in the following manner: (1) the air temperature tends to vary inversely with the pressure; (2) the sunshine varies directly with the pressure; (3) the air temperature tends to vary directly with the sunshine in the summer; (4) the dew point varies directly with the air temperature; (5) the wind velocity may vary directly with either extreme of pressure; (6) the precipitation may be inversely proportional to the pressure.

Some of these meteorological factors tend to increase the soil temperature and others to decrease it. High air temperature would tend to raise the temperature of the soil while low barometric pressure would favor greater evaporation and consequently the soil temperature would be kept down, all other conditions being equal. Sunshine varying directly with the pressure would have a very positive influence in the warming of the soil. The wind velocity would have a cooling effect both on account of the continual movement of cool air and because of its accelerating effect upon evaporation. Precipitation in early spring may and may not raise the soil temperature, but in the summer it would tend to lower it both because its temperature is lower than that of the soil, and because of the greater evaporation that ensues immediately after a rainfall.

Space does not permit to discuss and to point out in detail the influence of these elements singly or in combination on the present soil temperatures study. The reader can get a fair idea of their general run and influence by an examination of the charts. It will suffice to say that the only factor which the soil temperature follows very closely and overwhelmingly is the air temperature and hence, also, the dew point. The relationship of the soil temperature to the other elements is not very regular simply because their influences are secondary to that of the air temperature, also on account of the fact that they vary so much from day to day, also because their influences are opposed, hence the effect of the one is offset by the effect of the other.

Special attention may be called to the effect of rainfall and snow on the soil temperature. It is the common belief that both these elements exert a large influence on soil temperature. It is claimed that in the spring the precipitation tends to raise the soil temperature very perceptibly and in the winter the snow acts as a blanket over the soil and prevents its rapid loss of heat and thereby keeps its temperature high.

Data collected on both these factors have led to the conclusion that the rainfall has been given more importance than it really deserves but that the snow does perform well the function that is attributed to it. As to the former, it will be seen by referring to the charts for April and May that whenever it rained the temperature of both the

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air and the soil went down far below what it was before the rain began. This might have been an exceptional spring, but even then it does not appear that the rainfall could be very effective in raising the temperature of soil when it is considered (1) that it could be warmed up much faster on a rainless warm day, and (2) that the evaporation after the rainfall would tend to offset whatever warming effect the precipitation might have had.

From the theoretical standpoint snow ought to protect the soil from very severe freezing and thus keep its temperature higher and steadier. Its effect would seem to be analogous to that of a cover crop, cover of straw, etc. It ought to act as a blanket and reduce the rapid loss of heat, first by preventing the convection and wind current from coming in contact with soil, and second, because it is such a poor heat conductor. Where the thickness of the layer is considerable, snow is a very efficient agent in protecting the soil from very low temperature. An experiment that was conducted in the winter of 1912-1913 by placing two electrical resistance thermometers 6 inches into the ground, the area over one being kept free from snow and that over the other being kept covered with snow, shows a marked difference in temperature between the two cases. For instance, on March 5, when the minimum air temperature was—1° F., the temperature of the soil covered with about 5 inches of snow was 29.6° F., while that being free of snow was 23.6° F. On March 7, when the minimum air temperature registered—10° F., the temperature of the snow covered soil was 28.9° F., while that of the bare soil was 22.7° F. Before the snow had fallen, however, the temperature of both plots was the same and fluctuated to the same degree and with the same rapidity in both cases as the air temperature varied. The temperature records taken on the different types of soil and also on the soil with different amounts of organic matter throughout two winters show also very abundantly that whenever these soils were covered with a thick layer of snow their temperature remained much higher and steadier than when they were entirely unprotected, for the same or greater fall of air temperature. A typical example of this fact will be found in the months of February and March, 1913. During the first part of February, the soils were free of snow, and their temperature fell very low whenever the air temperature dropped down very low. On the 6th of that month, for instance, the minimum air temperature registered was 3° F., and the temperatures of some of the light soils went down as low as 12° F. On the 7th of March, however, the soils were covered with about 5 inches of snow. The minimum air temperature registered for this day was—10° F., while the temperature of all the soils remained along the freezing point, 32° F., showing very conclusively that snow tends to protect the soil from very rapid changes and low temperature, and it is therefore of great advantage in the winter time. This advantage, however, becomes a temporary disadvantage in the spring because a layer of snow will retard thawing on account of the large latent heat of fusion of snow.

This protecting effect of snow is undoubtedly greater on soils covered with straw or with growing vegetation which was planted in the fall than on bare soils, because the vegetation being very porous and com-

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ing between the surface soil and the snow prevents a very intimate contact between the two and thereby cuts down the rapid loss of heat.

### DAILY AND MONTHLY RANGE OF TEMPERATURE.

Mention has been made that the temperature of the different soil types under discussion, was recorded three times a day, at 7 a. m., 12 m., and 6 p. m. At these periods high and low temperatures were obtained at all three depths. These temperatures are probably not the absolute maximum and minimum. To obtain these it is necessary either to take records very often or continuously by means of thermographs or other continuous self recording instruments, because the absolute maximum and minimum temperatures of the various soils and of the different depths occur at different times. These low and high temperatures as obtained tri-urnally in the present work, however, are believed to be very close approximations to the absolute maximum and minimum, and especially for the upper 6-inch depth, which of course, for practical purposes, is the most important. The half-hour records which were taken at various times for the heat conductivity measurements, as well as the daily tri-urnal records, show that as a general rule the minimum occurred for the gravel and sand about 7 a. m., for the clay and loam about 12 m., and for the peat about 6 p. m. On the other hand the maximum was attained for the gravel and sand about 6 p. m., for the clay and loam a little later, and for the peat about 7 o'clock the following morning. The difference from the regular period to the time the highest or lowest reading was recorded is, therefore, not very large.

These high and low, or maximum and minimum, temperatures for all the different soils and for all three different depths are shown in the following tables and diagrams. The tables contain the daily and monthly high and low temperature for each soil and for each depth. On the diagrams are plotted the differences or amplitudes of these maximum and minima. The daily meteorological elements are also plotted and are the same as in the foregoing charts, except the air temperature, in which case the difference or amplitude is shown here instead of the average as in the preceding charts.

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TABLE 30.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, DECEMBER, 1911.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 32. | 33.5 | 36.9 | 31.7 | 33 8 | 36.9 | 31.9 | 34.9 | 37.9 | 31.9 | 34.9 | 37. | 32.1 | 34.5 | 37.9 |
| 1 Min. | 31.3 | 33. | 35.9 | 31. | 33.2 | 36.8 | 31.8 | 34.1 | 37.2 | 31.5 | 34.5 | 36.1 | 31.9 | 34.1 | 37.5 |
| 2 Max. | 32. | 33.5 | 36.5 | 32. | 34.1 | 37.4 | 32. | 34.7 | 37.7 | 32. | 35. | 36.9 | 32. | 34.5 | 37.5 |
| 2 Min. | 31.5 | 33. | 36.1 | 31.7 | 33.5 | 36.9 | 31.9 | 34.3 | 36.8 | 31.9 | 34. | 36.2 | 31.9 | 34. | 37.1 |
| 4 Max. | 32.2 | 33.5 | 36.7 | 32.2 | 34.3 | 36.9 | 32.2 | 34.6 | 37.1 | 32.2 | 34.8 | 36.9 | 32.1 | 34.5 | 37.9 |
| 4 Min. | 31.2 | 33.2 | 36.2 | 31.8 | 34. | 36.1 | 31.9 | 34.3 | 36.8 | 32. | 34.5 | 36.7 | 31.8 | 34. | 37.3 |
| 5 Max. | 32.5 | 34.5 | 36.5 | 32. | 34. | 37. | 32.1 | 35. | 37. | 33. | 35. | 36.8 | 32.6 | 34.6 | 37.5 |
| 5 Min. | 32.3 | 34. | 36.2 | 31.8 | 33.9 | 36.6 | 32. | 34.8 | 36.9 | 32.2 | 34.8 | 36.7 | 32.2 | 34.2 | 37. |
| 6 Max. | 32.4 | 33.9 | 36.5 | 32.1 | 34. | 36.7 | 32.8 | 34.5 | 37. | 32.6 | 34.6 | 36.5 | 32.1 | 34.5 | 37.2 |
| 6 Min. | 32.2 | 33.7 | 36.2 | 31.9 | 33.8 | 36.5 | 32.1 | 34.3 | 36.8 | 31.9 | 34.2 | 36.3 | 32. | 34.1 | 37. |
| 7 Max. | 31.8 | 33.5 | 36. | 31.7 | 34. | 36.1 | 32.1 | 34. | 36.8 | 32.1 | 34.1 | 36.3 | 32.1 | 34.1 | 37.2 |
| 7 Min. | 31.7 | 33.1 | 35.7 | 31.2 | 32.7 | 35.8 | 31.5 | 33.9 | 36.3 | 31.9 | 33.8 | 35.6 | 31.5 | 33.6 | 36.8 |
| 8 Max. | 32.5 | 34. | 36.2 | 33.4 | 34.2 | 36.8 | 32.7 | 34.8 | 37.2 | 33. | 34.9 | 36.5 | 32.5 | 35. | 37.2 |
| 8 Min. | 32.1 | 33.8 | 36. | 32.2 | 34. | 36.3 | 32.3 | 34.7 | 36.8 | 32.5 | 34.4 | 36. | 32. | 34. | 36.9 |
| 9 Max. | 40.5 | 39.2 | 38.6 | 41.8 | 39.5 | 38.2 | 33.9 | 35.5 | 37.3 | 36. | 36.5 | 37.4 | 32.8 | 34.9 | 37. |
| 9 Min. | 37. | 36.9 | 37. | 37.5 | 37. | 37.2 | 32.7 | 34 8 | 37.3 | 34.8 | 35.7 | 36.4 | 32.2 | 34.2 | 37. |
| 11 Max. | 41.9 | 42.1 | 41.9 | 41.5 | 41.8 | 41.4 | 41. | 40. | 39.7 | 41.7 | 41. | 40.2 | 32.5 | 34.2 | 37.2 |
| 11 Min. | 41.8 | 42. | 41. | 41. | 41.5 | 40.5 | 40.2 | 39. | 38. | 41.5 | 40. | 39.5 | 32. | 33.5 | 36.5 |
| 12 Max. | 38.2 | 40.4 | 41.5 | 37.5 | 39.4 | 41.2 | 39. | 40.2 | 41. | 39.5 | 41. | 41.2 | 32.6 | 34.8 | 38. |
| 12 Min. | 38. | 40. | 40.8 | 37.2 | 38.9 | 40.8 | 38.9 | 40.1 | 40. | 39.2 | 40.2 | 40.8 | 32.4 | 34.3 | 37. |
| 13 Max. | 37. | 36.7 | 40.5 | 36.1 | 36. | 40.6 | 37.8 | 39.5 | 40.8 | 37.3 | 40. | 41. | 33.2 | 35.4 | 38.2 |
| 13 Min. | 36.7 | 37.5 | 39.2 | 35. | 37.1 | 39.1 | 36. | 38.8 | 40. | 36.2 | 38.2 | 39.8 | 32.1 | 35. | 38. |
| 14 Max. | 34.9 | 36.4 | 39.1 | 34. | 36.4 | 38.8 | 35.7 | 38. | 39. | 35. | 37.9 | 39.3 | 33. | 35.8 | 38.2 |
| 14 Min. | 33. | 34.9 | 37.4 | 32.2 | 34.5 | 37.8 | 33.3 | 36.8 | 38.2 | 33.1 | 35.4 | 38.2 | 32. | 34. | 38. |
| 15 Max. | 33.7 | 35.4 | 38. | 33.3 | 35.1 | 38.1 | 34.5 | 37.1 | 39.1 | 34.1 | 36.6 | 38.5 | 32.9 | 35. | 37.9 |
| 15 Min. | 33. | 35. | 37.6 | 33. | 34.5 | 37.7 | 33.9 | 36.4 | 38.7 | 33.9 | 36.5 | 38. | 32.3 | 34.6 | 37.8 |
| 16 Max. | 34. | 35.7 | 38. | 34. | 35.6 | 38.3 | 34.2 | 36.6 | 39. | 34.1 | 36.7 | 38.2 | 33.4 | 35.7 | 38.7 |
| 16 Min. | 33.5 | 35.2 | 37.3 | 33.5 | 35. | 37.8 | 33.6 | 36.5 | 38.9 | 33.9 | 36.6 | 38. | 33.1 | 35.4 | 38.5 |
| 18 Max. | 34. | 35.9 | 37.9 | 34.2 | 36. | 38.2 | 33.9 | 36.2 | 38.3 | 34.2 | 36.4 | 38. | 33.5 | 39.1 | 38.4 |
| 18 Min. | 33.9 | 35.1 | 37.7 | 33.8 | 35.2 | 37.8 | 33.7 | 36. | 38.1 | 34.1 | 36. | 37.8 | 33. | 35.7 | 38.1 |
| 19 Max. | 35.2 | 36.4 | 38.1 | 34.9 | 36.2 | 38.8 | 35. | 36.7 | 39. | 34.9 | 36.8 | 38.2 | 34.2 | 36.4 | 39. |
| 19 Min. | 34.8 | 35.8 | 37.9 | 34.4 | 36. | 38.1 | 34.1 | 36.5 | 38.8 | 34.7 | 36.8 | 38. | 33.9 | 35.9 | 38.9 |
| 20 Max. | 34.8 | 36.8 | 38. | 34.9 | 35.6 | 37.9 | 33.9 | 36.5 | 38.8 | 34.8 | 36.5 | 39.1 | 33.9 | 36. | 39. |
| 20 Min. | 33.1 | 34.5 | 36.8 | 33. | 34.8 | 37. | 33.1 | 35.5 | 37.6 | 33.2 | 35.6 | 37. | 33. | 35. | 37.8 |
| 21 Max. | 33.9 | 35.2 | 37.2 | 33.5 | 35. | 37. | 32.8 | 35.9 | 38.5 | 33.8 | 35.9 | 37.4 | 33. | 35.1 | 38.2 |
| 21 Min. | 32.5 | 33.8 | 35.8 | 32.1 | 33.9 | 36.5 | 32.2 | 34.4 | 36.6 | 32. | 34.6 | 36. | 31.8 | 34. | 36.5 |
| 22 Max. | 34.4 | 34.1 | 36. | 35. | 34.9 | 36. | 32.2 | 34.5 | 36.5 | 33.5 | 34.8 | 36.1 | 31.9 | 33.9 | 36.9 |
| 22 Min. | 32. | 33.1 | 35.4 | 32.1 | 33.5 | 35.7 | 32. | 33.4 | 36. | 32.3 | 34. | 35.5 | 31.7 | 33.5 | 36.1 |
| 23 Max. | 33.9 | 34.9 | 36.8 | 33. | 34.5 | 36.5 | 32.5 | 34.5 | 36.1 | 33.2 | 35. | 35.9 | 31.8 | 33.6 | 36.5 |
| 23 Min. | 33. | 34.5 | 36. | 32.5 | 34.5 | 36.4 | 32.5 | 34.5 | 36.1 | 33.1 | 34.5 | 35.8 | 31.5 | 33.2 | 36.2 |
| 26 Max. | 32.5 | 33.9 | 35.9 | 32.5 | 34.1 | 36.5 | 31.9 | 34.7 | 36.1 | 32.5 | 34.1 | 36. | 31.9 | 33.5 | 36.1 |
| 26 Min. | 31.9 | 33. | 35.3 | 31. | 33.1 | 35.9 | 31.3 | 33.5 | 35.8 | 31.9 | 33.7 | 35.5 | 31.5 | 33.2 | 36. |
| 27 Max. | 32.3 | 34.9 | 35.6 | 33.8 | 34.8 | 36.1 | 32. | 34.7 | 36.5 | 33.3 | 34.7 | 35.6 | 32.8 | 34. | 36.3 |
| 27 Min. | 31.4 | 32.8 | 33.8 | 31.6 | 33.3 | 35.1 | 31.3 | 32.4 | 35.5 | 31.8 | 32.7 | 34.4 | 31.2 | 32.9 | 34.5 |
| 28 Max. | 32.4 | 33.3 | 35.4 | 31.8 | 33.6 | 36.4 | 32.9 | 34.5 | 36.6 | 33.7 | 35.2 | 35.7 | 32 6 | 34.3 | 36.4 |
| 28 Min. | 31.6 | 32.2 | 34 9 | 30.5 | 32.9 | 35.6 | 32. | 34.1 | 35.6 | 32.1 | 34.2 | 35.1 | 31.8 | 33.9 | 35.8 |
| 29 Max. | 31.3 | 32.4 | 35. | 31.2 | 32.7 | 35.9 | 31.4 | 33.5 | 35.8 | 31.1 | 33.7 | 35.1 | 32.2 | 33.9 | 36.7 |
| 29 Min. | 29.7 | 30.8 | 33. | 28.9 | 31.9 | 35. | 30.5 | 33.1 | 35.7 | 30.8 | 33.2 | 34.8 | 31.5 | 32.8 | 35.4 |
| 30 Max. | 30.6 | 31.8 | 33.6 | 30.5 | 31.6 | 34.4 | 30.7 | 32.9 | 35. | 30.6 | 32.7 | 34.4 | 31.9 | 33.1 | 36.1 |
| 30 Min. | 29 7 | 29.9 | 33.1 | 30. | 31.3 | 34.2 | 29.9 | 32.3 | 34.4 | 30.1 | 32.2 | 34. | 30.5 | 32.6 | 34.8 |
| Monthly range | 1.31 | 0.92 | 0.64 | 1.09 | 0.75 | 0.60 | 0.66 | 0.62 | 0.60 | 0.69 | 0.72 | 0.64 | 0.60 | 0.61 | 0.60 |

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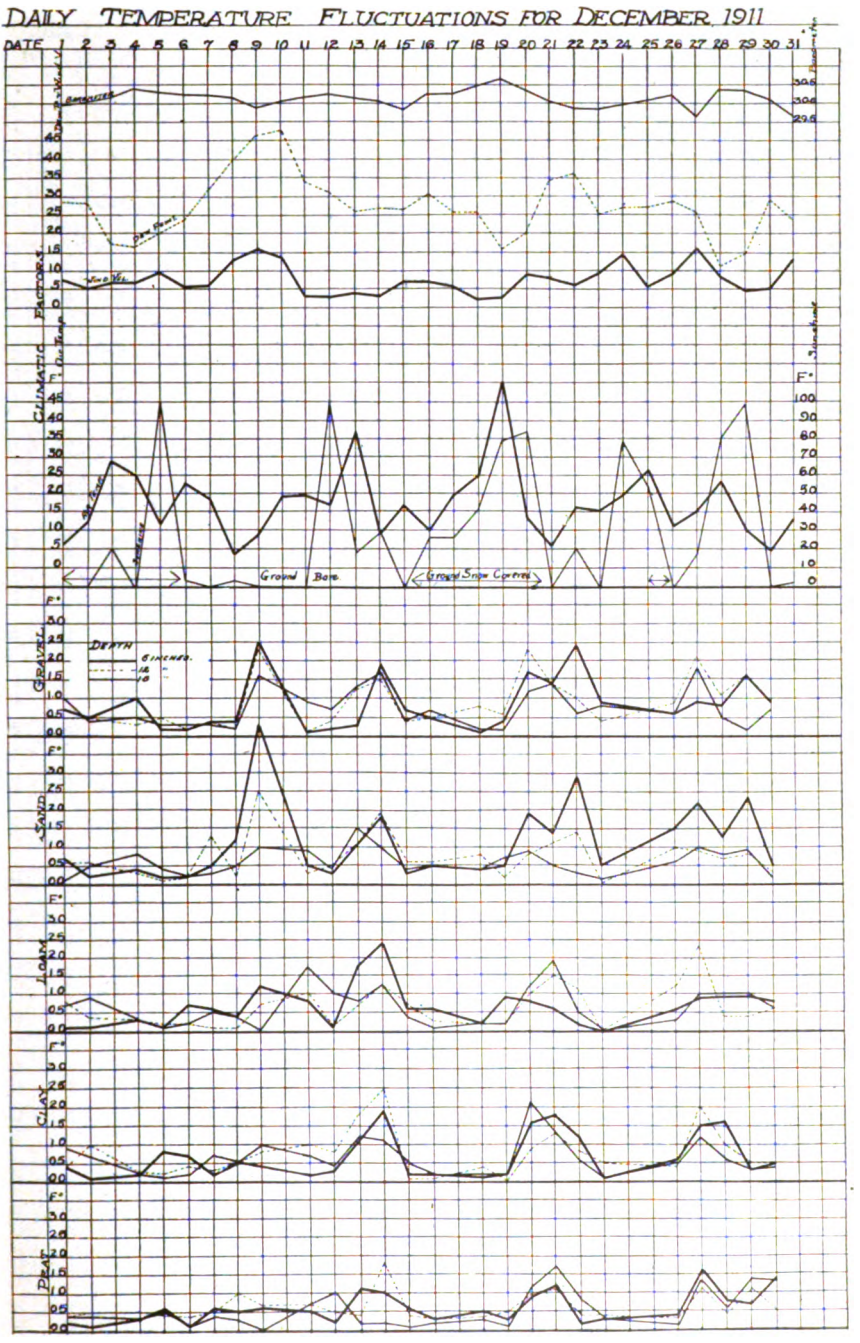


FIG. 16.

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TABLE 31.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, JAN. 1912.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max... | 30.7 | 31.9 | 35. | 30.1 | 32.6 | 34.5 | 30.8 | 32.7 | 34.8 | 31.2 | 33.3 | 34.9 | 32.6 | 33. | 35.4 |
| 1 Min.... | 27.8 | 29. | 31.6 | 28.2 | 30.4 | 31.9 | 28.7 | 30.8 | 32.5 | 29.1 | 31.9 | 33.7 | 30.5 | 32. | 34.9 |
| 2 Max... | 28.3 | 31.1 | 33.4 | 27.7 | 31.4 | 33.8 | 29.8 | 32.1 | 35. | 30.4 | 32.2 | 33.5 | 30. | 31.8 | 35.1 |
| 2 Min.... | 26.7 | 30. | 32.3 | 25.6 | 29.6 | 32.7 | 28.3 | 30.6 | 33.2 | 28.1 | 30.7 | 31. | 28.6 | 30.1 | 33.6 |
| 3 Max... | 24.4 | 28.6 | 32.1 | 22. | 30.3 | 33.5 | 27.7 | 32.2 | 35.3 | 28.4 | 31.1 | 33.8 | 29.2 | 31.6 | 34.5 |
| 3 Min.... | 19.3 | 23.4 | 25.2 | 19.5 | 24.9 | 28.7 | 25.4 | 29.6 | 30.3 | 27. | 30.6 | 32.1 | 28.5 | 30.9 | 33.6 |
| 4 Max... | 26.2 | 29.2 | 33.5 | 24.3 | 29.9 | 34.3 | 28.0 | 32.9 | 35.5 | 28.8 | 32.8 | 34.5 | 29.9 | 33.2 | 35.9 |
| 4 Min.... | 25.9 | 29. | 33.1 | 24. | 29.5 | 34. | 28.8 | 32.8 | 35.2 | 28.5 | 32.5 | 34.5 | 29.8 | 33. | 35.8 |
| 5 Max... | 21.4 | 26.8 | 33.1 | 19.5 | 27.8 | 33.5 | 26.5 | 32.6 | 35. | 26.8 | 32. | 34.1 | 27. | 32.7 | 35.3 |
| 5 Min.... | 20.6 | 26. | 32.3 | 17. | 26.3 | 33.2 | 24.9 | 31.9 | 35. | 24.9 | 31.8 | 33.8 | 24.4 | 32.4 | 35.2 |
| 6 Max... | 19. | 24.9 | 32.2 | 15.3 | 25.7 | 33.1 | 23.5 | 31.9 | 34.9 | 23.8 | 31.8 | 34.1 | 21.5 | 32.2 | 35.5 |
| 6 Min.... | 18.9 | 23.7 | 31. | 14.4 | 24. | 32.1 | 23. | 31.5 | 34. | 23.3 | 31.2 | 33.5 | 21. | 32.1 | 34.9 |
| 8 Max... | 21.2 | 24. | 30. | 18. | 23.7 | 31.5 | 22.6 | 29.6 | 33.7 | 22.2 | 29. | 33.2 | 20.5 | 31.9 | 34.1 |
| 8 Min.... | 18.9 | 22.8 | 29.5 | 15. | 22.5 | 31.3 | 21.5 | 29.5 | 33.5 | 21.4 | 28.8 | 32.1 | 19. | 31.5 | 34. |
| 9 Max... | 25. | 27. | 30.4 | 22.1 | 25.8 | 31.6 | 25. | 29. | 32.6 | 24.2 | 29.2 | 32. | 22. | 31. | 34. |
| 9 Min.... | 23.7 | 25.8 | 30.1 | 20. | 25.3 | 31.4 | 24. | 28.7 | 32.5 | 23.1 | 27.4 | 31.5 | 21.5 | 31. | 33.7 |
| 10 Max... | 25.6 | 27.6 | 30.8 | 23.2 | 27. | 31.5 | 25.2 | 29.4 | 32.8 | 24.8 | 28.7 | 31.3 | 23.4 | 31. | 34. |
| 10 Min.... | 25. | 27.3 | 30.5 | 23.1 | 26.8 | 31. | 25. | 29. | 32.4 | 24.5 | 28.3 | 31.2 | 23. | 30.6 | 33.5 |
| 11 Max... | 26. | 27.9 | 30.4 | 23.9 | 28. | 31.8 | 26.6 | 29.2 | 33. | 24.9 | 28.1 | 31.6 | 24. | 30.4 | 33.5 |
| 11 Min.... | 25.5 | 27.8 | 30.2 | 23.7 | 27.2 | 31. | 25.8 | 29. | 32.3 | 24.4 | 28. | 31. | 23.9 | 30. | 33.4 |
| 12 Max... | 28.3 | 27.9 | 30.3 | 24.8 | 28.2 | 31.1 | 26.1 | 29.2 | 31.4 | 24.9 | 28.1 | 30.9 | 23.6 | 29. | 33. |
| 12 Min.... | 25.8 | 27. | 30. | 23.1 | 27. | 30.1 | 25.1 | 29. | 31.1 | 24. | 27.5 | 30.6 | 22.8 | 28.8 | 32.8 |
| 13 Max... | 24.6 | 27. | 30.1 | 23.4 | 27.5 | 30.3 | 25.2 | 28.2 | 31.3 | 22.3 | 27.5 | 30.5 | 22. | 28.2 | 32.4 |
| 13 Min.... | 24.3 | 26.2 | 29. | 23. | 26.9 | 30.2 | 24.8 | 28.1 | 31.1 | 22.2 | 26.8 | 30.4 | 21.7 | 27.2 | 32. |
| 15 Max... | 25.6 | 27.9 | 30.8 | 24.8 | 27.9 | 30.8 | 25.6 | 28.7 | 31.8 | 24.4 | 27.7 | 30.7 | 24.4 | 28.6 | 32.7 |
| 15 Min.... | 25.2 | 27.9 | 30.5 | 24.5 | 27.6 | 30.5 | 25.3 | 28.5 | 31.4 | 24.1 | 27.4 | 30.2 | 24.1 | 28.4 | 32.4 |
| 16 Max... | 25.4 | 27.6 | 30.3 | 24. | 27.7 | 30.5 | 25.5 | 28.8 | 31.5 | 24.5 | 27.3 | 30. | 23.5 | 28.4 | 32.4 |
| 16 Min.... | 25. | 27.5 | 30.3 | 23.9 | 27.7 | 30.5 | 25.3 | 28.7 | 31.4 | 24.3 | 27.2 | 30. | 23.2 | 28. | 32.3 |
| 17 Max... | 25. | 27.3 | 30.2 | 24.6 | 27.5 | 30.4 | 25.5 | 28.8 | 31.3 | 25. | 27.3 | 30.2 | 23.7 | 28.1 | 32.3 |
| 17 Min.... | 24.4 | 26. | 29. | 23.2 | 26.2 | 29.5 | 25.1 | 28.6 | 30.9 | 24.5 | 27. | 29.9 | 23.2 | 27.9 | 32.1 |
| 18 Max... | 29. | 30. | 31. | 27.7 | 29. | 31.4 | 27.3 | 29.1 | 31.9 | 27. | 28.5 | 30.6 | 28.8 | 28.8 | 32.8 |
| 18 Min.... | 27. | 28.3 | 30.8 | 25. | 28.5 | 31.2 | 26.5 | 28.9 | 31.5 | 26. | 27.7 | 30.3 | 25.7 | 28.6 | 32.5 |
| 19 Max... | 29.5 | 30. | 31. | 28.3 | 29.9 | 31.5 | 27.5 | 29.3 | 31.9 | 27.6 | 28.6 | 30.5 | 27.1 | 28.8 | 32.8 |
| 19 Min.... | 29. | 29.7 | 30.9 | 27.9 | 29.8 | 31.1 | 27.3 | 29.1 | 31.4 | 27.3 | 28.6 | 30.4 | 26.6 | 28.7 | 32.6 |
| 20 Max... | 27.6 | 28.7 | 30.8 | 26.3 | 29. | 31.3 | 27. | 28.9 | 31.2 | 27. | 29.6 | 30.3 | 25.5 | 28.6 | 32. |
| 20 Min.... | 27. | 27.5 | 30. | 25. | 28.6 | 29.9 | 25.7 | 28.4 | 30. | 26. | 27.9 | 29.6 | 23. | 27.7 | 31.3 |
| 22 Max... | 28.2 | 28.3 | 30.8 | 27. | 29.1 | 30.8 | 26.2 | 29.1 | 31. | 27.2 | 29.2 | 30.3 | 26.3 | 28.4 | 32. |
| 22 Min.... | 27. | 27.8 | 29.9 | 25.5 | 28.3 | 30. | 26. | 28.3 | 30.1 | 26.9 | 28.1 | 29.2 | 25.3 | 27.1 | 31.6 |
| 23 Max... | 28.4 | 29.3 | 30.9 | 27.7 | 29.5 | 30.9 | 27.1 | 29.1 | 31.1 | 28. | 29.1 | 30.3 | 28.8 | 28.5 | 32. |
| 23 Min.... | 27.8 | 28.8 | 30. | 27. | 28.5 | 30.4 | 26.5 | 28.5 | 30.6 | 27.8 | 29. | 30. | 26.5 | 28.5 | 31.8 |
| 24 Max... | 29.1 | 30. | 31.4 | 28.4 | 30.2 | 31.6 | 28.4 | 30. | 31.7 | 28.7 | 30. | 31.1 | 27.4 | 29.2 | 32.3 |
| 24 Min.... | 28.4 | 29.8 | 31.3 | 28. | 30. | 31.5 | 28. | 29.9 | 31.3 | 28.4 | 29.8 | 30.5 | 27.2 | 29. | 32. |
| 25 Max... | 29. | 30. | 31.7 | 28. | 30.1 | 31.7 | 28.2 | 30. | 31.8 | 28.5 | 29.7 | 31.2 | 27.2 | 29.1 | 32.3 |
| 25 Min.... | 28.7 | 29.7 | 31.5 | 27.7 | 29.9 | 31.5 | 28. | 29.9 | 31.4 | 28.2 | 29.7 | 30.9 | 26.9 | 29. | 32. |
| 26 Max... | 28.6 | 29.6 | 31.5 | 27.5 | 30. | 31.5 | 28.1 | 30. | 31.6 | 28.3 | 30. | 31.2 | 27.2 | 29.5 | 32.4 |
| 26 Min.... | 28.5 | 29.4 | 31. | 27.3 | 29.9 | 31.3 | 28. | 29.9 | 31.5 | 28.1 | 29.9 | 30.9 | 27. | 29. | 32.2 |
| 27 Max... | 29. | 30. | 31.3 | 27.7 | 30.2 | 31.6 | 28.2 | 30. | 31.5 | 28.6 | 30. | 31. | 27.4 | 29.5 | 32.1 |
| 27 Min.... | 28.8 | 29.8 | 31. | 27.5 | 30. | 31.6 | 28. | 29.8 | 31.3 | 28.4 | 29.8 | 30.6 | 26.9 | 29.1 | 31.8 |
| 29 Max... | 28.5 | 29.4 | 31.1 | 27.6 | 29.8 | 31.2 | 27.9 | 29.4 | 31.2 | 28.4 | 29.6 | 30.7 | 27. | 28.8 | 31.8 |
| 29 Min.... | 27.9 | 28.7 | 30. | 26.8 | 28.3 | 30.7 | 27.3 | 28.7 | 30.5 | 27.8 | 28.8 | 29.9 | 26.6 | 28.4 | 31. |
| 30 Max... | 28.2 | 29.2 | 30.2 | 27.2 | 28.9 | 31. | 27.5 | 28.9 | 30.9 | 28 2 | 29.1 | 30.2 | 28.9 | 28.5 | 31.4 |
| 30 Min.... | 27.7 | 28.9 | 29.4 | 26.5 | 27.6 | 30.1 | 26.9 | 28.1 | 29.5 | 27.2 | 28.4 | 29.5 | 26.2 | 27.8 | 30.1 |
| 31 Max... | 29.2 | 29.9 | 31. | 28.2 | 29.4 | 31. | 28. | 29.1 | 30.9 | 28.6 | 29.1 | 30.1 | 27.8 | 29. | 31. |
| 31 Min.... | 28.8 | 29.5 | 30.3 | 27.6 | 29. | 30.9 | 27.9 | 28.9 | 30.8 | 28.5 | 29. | 30. | 27.4 | 28.8 | 30.8 |
| Monthly range.... | 0.94 | 0.89 | 0.92 | 1.10 | 0.95 | 0.72 | 0.70 | 0.50 | 0.75 | 0.70 | 0.52 | 0.58 | 0.76 | 0.45 | 0.41 |

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DAILY TEMPERATURE FLUCTUATIONS FOR JANUARY 1912

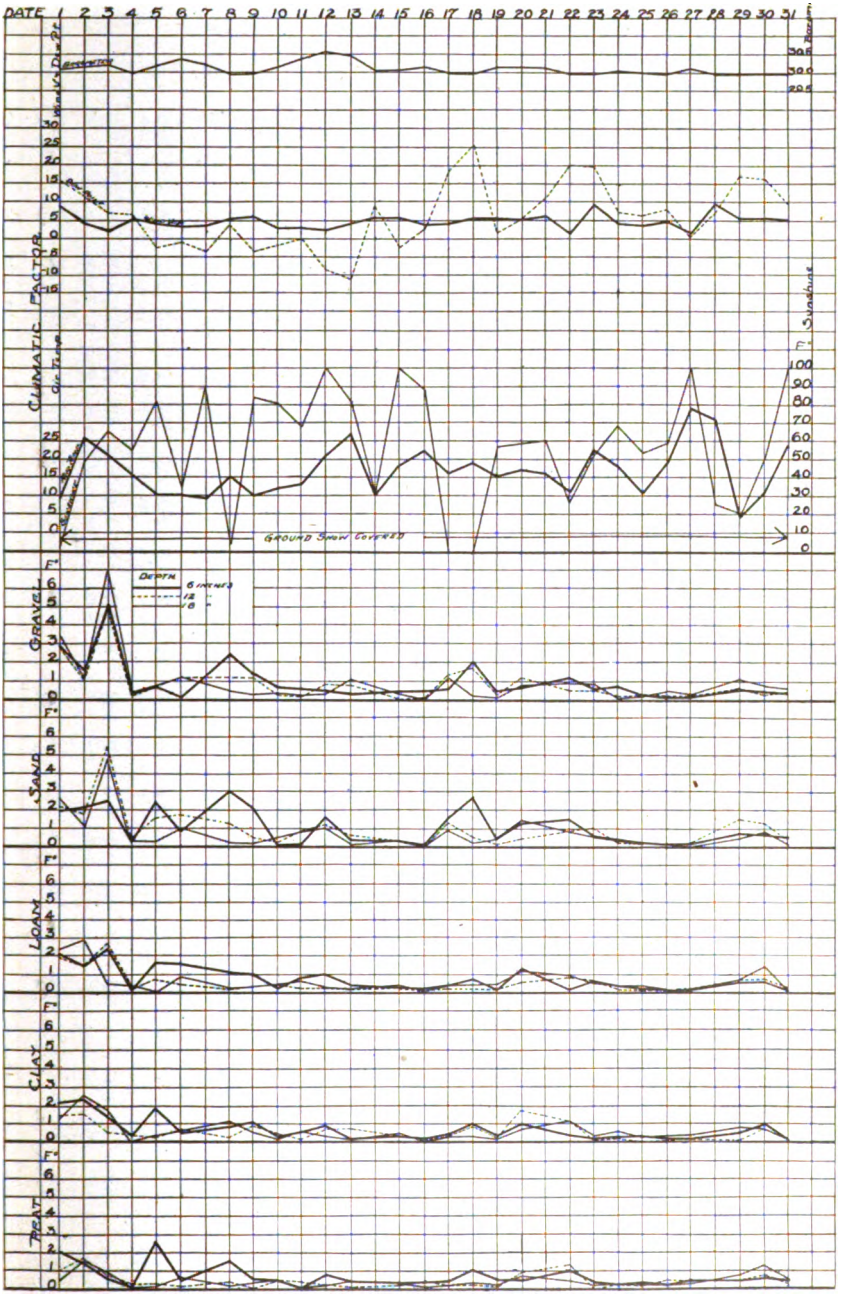


FIG. 17.

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TABLE 32.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, FEBRUARY, 1912.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max... | 29. | 29.9 | 31. | 27.7 | 29.5 | 31.2 | 28.7 | 29.2 | 31. | 28.6 | 29.3 | 30.4 | 27.5 | 28.0 | 31.2 |
| 1 Min.... | 28.8 | 29.7 | 30.6 | 27.2 | 29.4 | 30.9 | 27.6 | 28.9 | 30.8 | 28.2 | 29.1 | 30.2 | 27. | 28.6 | 31. |
| 2 Max... | 28.9 | 30. | 31.3 | 27.8 | 29.7 | 31.1 | 28.5 | 29.2 | 31. | 28.8 | 29.5 | 30.5 | 27.5 | 28.8 | 31.4 |
| 2 Min.... | 28.8 | 29.8 | 30.8 | 27.3 | 29.4 | 30.9 | 27.8 | 28.9 | 30.8 | 28. | 29. | 30. | 26.8 | 28.2 | 31. |
| 3 Max... | 29. | 30. | 31.2 | 27.6 | 29.6 | 31. | 28.5 | 29.3 | 31. | 28.8 | 29.8 | 30.7 | 27.4 | 28.3 | 31.5 |
| 3 Min.... | 28.4 | 29.5 | 30.6 | 27. | 29. | 30.5 | 28. | 28.8 | 30.3 | 28.4 | 29.4 | 30.4 | 27. | 28.8 | 30.8 |
| 5 Max... | 28.6 | 30. | 31.6 | 27.5 | 30. | 31.4 | 28.1 | 36.1 | 31.3 | 28.5 | 30.1 | 31. | 27.5 | 29. | 31.5 |
| 5 Min.... | 28.4 | 29.6 | 30.6 | 27.3 | 29.5 | 30.8 | 28. | 29.9 | 30.5 | 28. | 29.8 | 30.2 | 27.1 | 28. | 30.4 |
| 6 Max... | 28.5 | 28.8 | 31.7 | 27.5 | 30. | 31.4 | 28.1 | 30. | 31.6 | 28.7 | 30.4 | 31.1 | 27. | 29.2 | 32. |
| 6 Min.... | 28.4 | 29.7 | 31.3 | 27. | 29.8 | 31.3 | 27.9 | 29.8 | 31.5 | 28.6 | 30.3 | 31. | 26.9 | 29.1 | 31.8 |
| 7 Max... | 28.5 | 30. | 31. 1 | 27.2 | 29.9 | 31.3 | 28.2 | 29.6 | 31.6 | 28.6 | 30.2 | 31. | 27.1 | 29. | 31.9 |
| 7 Min.... | 28.4 | 29.9 | 31. | 26.9 | 29.7 | 31.1 | 28. | 29.6 | 31.2 | 28.5 | 29.9 | 30.8 | 26.9 | 28.9 | 31.9 |
| 8 Max... | 28.4 | 29.4 | 30.6 | 27.2 | 29.9 | 31.2 | 27.6 | 29.1 | 30.9 | 28.1 | 29.7 | 30.4 | 27.1 | 29. | 31.7 |
| 8 Min.... | 28.1 | 29.2 | 30.5 | 26.8 | 29.7 | 31. | 27.5 | 28.9 | 30.7 | 27.8 | 29.4 | 30.2 | 26.8 | 28.8 | 31.3 |
| 9 Max... | 28.7 | 29.6 | 31.2 | 26.9 | 36. | 31.7 | 28.1 | 30.3 | 31.5 | 28.6 | 29.6 | 30.6 | 27.3 | 29.3 | 32.1 |
| 9 Min.... | 28.4 | 29.2 | 30.9 | 26.3 | 29.5 | 31.4 | 27.6 | 29.5 | 31. | 28.3 | 29.4 | 30.3 | 27.2 | 29.1 | 31.9 |
| 10 Max... | 28.4 | 29. | 31. | 25.5 | 29. | 31.4 | 27.2 | 29.7 | 30.9 | 27.1 | 29.3 | 30.5 | 27. | 28.8 | 31.3 |
| 10 Min.... | 26.8 | 28.9 | 30.9 | 22. | 28. | 31. | 25.5 | 29.4 | 30.8 | 26. | 28.9 | 30.2 | 26.6 | 28.7 | 31. |
| 12 Max... | 28.1 | 29.1 | 31. | 25.2 | 28.3 | 31.3 | 28.3 | 29.3 | 30.9 | 28.4 | 29. | 30.2 | 26.7 | 28.0 | 31.7 |
| 12 Min.... | 27.9 | 29. | 30.9 | 25. | 28.1 | 30.4 | 26.1 | 29. | 30.9 | 26.2 | 28.8 | 30.1 | 26.2 | 28.4 | 31.5 |
| 13 Max... | 27.9 | 29. | 30.8 | 25.3 | 28.2 | 30.7 | 26.8 | 28.7 | 30.6 | 26.2 | 28.4 | 29.9 | 26.8 | 28.6 | 31.2 |
| 13 Min.... | 27.5 | 28.9 | 30.6 | 25.2 | 27.9 | 30.3 | 26.5 | 28.4 | 30.3 | 25.9 | 28.3 | 29.9 | 26.7 | 28.5 | 31.2 |
| 14 Max... | 28.3 | 29. | 30.7 | 25.9 | 28.7 | 30.3 | 26.3 | 28.5 | 30.8 | 26.4 | 28.5 | 30. | 27. | 28.5 | 31.6 |
| 14 Min.... | 27.9 | 28.9 | 30 5 | 25.3 | 28.4 | 30.3 | 26.1 | 28.3 | 30.6 | 26.3 | 28.3 | 30. | 27. | 28.3 | 31.3 |
| 15 Max... | 28.6 | 29.6 | 30.7 | 27.4 | 29.1 | 30.6 | 27. | 28.8 | 31. | 27. | 28.7 | 30.2 | 27.6 | 28.7 | 31.6 |
| 15 Min.... | 28 8 | 29 3 | 30 5 | 26 3 | 29. | 30.3 | 26.9 | 28.4 | 30.8 | 27. | 28.7 | 29.9 | 27.3 | 28.5 | 31. |
| 16 Max... | 29. | 29.5 | 30.4 | 28.2 | 29.4 | 30.7 | 27.4 | 28.5 | 30.5 | 27.6 | 28.9 | 30.1 | 28.1 | 28.9 | 31.2 |
| 16 Min.... | 28.9 | 29.5 | 30.2 | 27.9 | 29.2 | 30. | 27.1 | 28.3 | 30. | 27.3 | 28.8 | 29.1 | 27.6 | 28.7 | 31. |
| 17 Max... | 28.6 | 29.3 | 30.2 | 28.2 | 29.5 | 30.4 | 27.4 | 28.3 | 29.7 | 27.8 | 28.6 | 29.5 | 28.3 | 29. | 31.1 |
| 17 Min.... | 28.3 | 28 8 | 29.9 | 27.9 | 28.6 | 30. | 27.3 | 28.1 | 29.5 | 27.1 | 28.5 | 29.2 | 28.2 | 28.9 | 30.8 |
| 19 Max... | 30.5 | 31. | 31.7 | 31. | 31. | 31.7 | 29.3 | 36.1 | 30.4 | 29.2 | 29.4 | 30.3 | 29.6 | 30.1 | 31.1 |
| 19 Min.... | 28.8 | 29 3 | 30.2 | 29.2 | 29.7 | 30.8 | 28.2 | 29. | 30. | 27.8 | 28. | 29.9 | 28.9 | 29.4 | 31. |
| 20 Max... | 30.7 | 31.1 | 31.5 | 31. | 31.2 | 31.6 | 29.5 | 30.2 | 31.1 | 29.9 | 30. | 30.8 | 30.3 | 30.2 | 31.3 |
| 20 Min.... | 30. | 30.5 | 31.2 | 30.8 | 31. | 30.9 | 29. | 29.5 | 30.5 | 29.4 | 29.5 | 30.7 | 29.6 | 29.8 | 31. |
| 23 Max... | 29.5 | 30. | 30.8 | 30.2 | 30.4 | 31.2 | 29.2 | 29.6 | 30.6 | 28.9 | 30.1 | 30.4 | 29.1 | 30.3 | 31.5 |
| 23 Min.... | 29.4 | 29 9 | 30.5 | 30.2 | 30.3 | 30.7 | 28.5 | 29.5 | 30 3 | 28.8 | 29.5 | 30.4 | 28. | 29.2 | 31.3 |
| 24 Max... | 30.4 | 31.5 | 31.2 | 31.7 | 31.4 | 31.1 | 30.1 | 30.4 | 31.3 | 30.6 | 30.7 | 31. | 29.5 | 30.5 | 30.8 |
| 24 Min.... | 30.1 | 30 4 | 30.4 | 30.6 | 30.3 | 30.5 | 29.8 | 30.2 | 30. | 29.4 | 29.5 | 30.2 | 29.4 | 29.5 | 30.6 |
| 26 Max... | 31.6 | 31.5 | 31.6 | 31.5 | 31.7 | 31.9 | 29.7 | 30.6 | 31.4 | 30.6 | 31.4 | 31. | 30.8 | 30.3 | 31.9 |
| 26 Min.... | 30.3 | 30.5 | 30.6 | 30.5 | 30.5 | 31. | 29. | 29.7 | 30.3 | 29.3 | 29.6 | 30.2 | 29.4 | 29.4 | 30.2 |
| 27 Max... | 30.6 | 31.2 | 31.7 | 31.2 | 31.9 | 32. | 30.1 | 30.6 | 31.4 | 30.3 | 31. | 31.2 | 30.0 | 30.9 | 31.9 |
| 27 Min.... | 30.4 | 31. | 30.9 | 30 8 | 31. | 31. | 29.4 | 30. | 31. | 30. | 30.2 | 30.7 | 30. | 30. | 31.5 |
| 28 Max... | 31. | 31.3 | 31.3 | 31.2 | 31.4 | 31.8 | 29.6 | 30.2 | 31.2 | 30.2 | 30.6 | 30.9 | 30.3 | 30.4 | 31.5 |
| 28 Min.... | 30 9 | 31.1 | 31 1 | 31. | 30.9 | 31.3 | 29 8 | 30.1 | 30.9 | 30.1 | 30 3 | 30.9 | 30.3 | 30.2 | 31.4 |
| 29 Max... | 31.1 | 31.4 | 31.5 | 31. | 31.3 | 31.6 | 30.1 | 30.7 | 31.4 | 30.6 | 30.6 | 31.3 | 30.8 | 30.5 | 31.5 |
| 29 Min.... | 31. | 31.1 | 31.4 | 31. | 31.2 | 31.5 | 29.9 | 30.3 | 31. | 30.3 | 30.6 | 31.2 | 30.5 | 30.4 | 31.3 |
| Monthly range.... | 0.42 | 0.37 | 0.41 | 0.63 | 0.48 | 0.46 | 0.46 | 0.37 | 0.42 | 0.47 | 0.44 | 0.32 | 0.43 | 0.39 | 0.36 |

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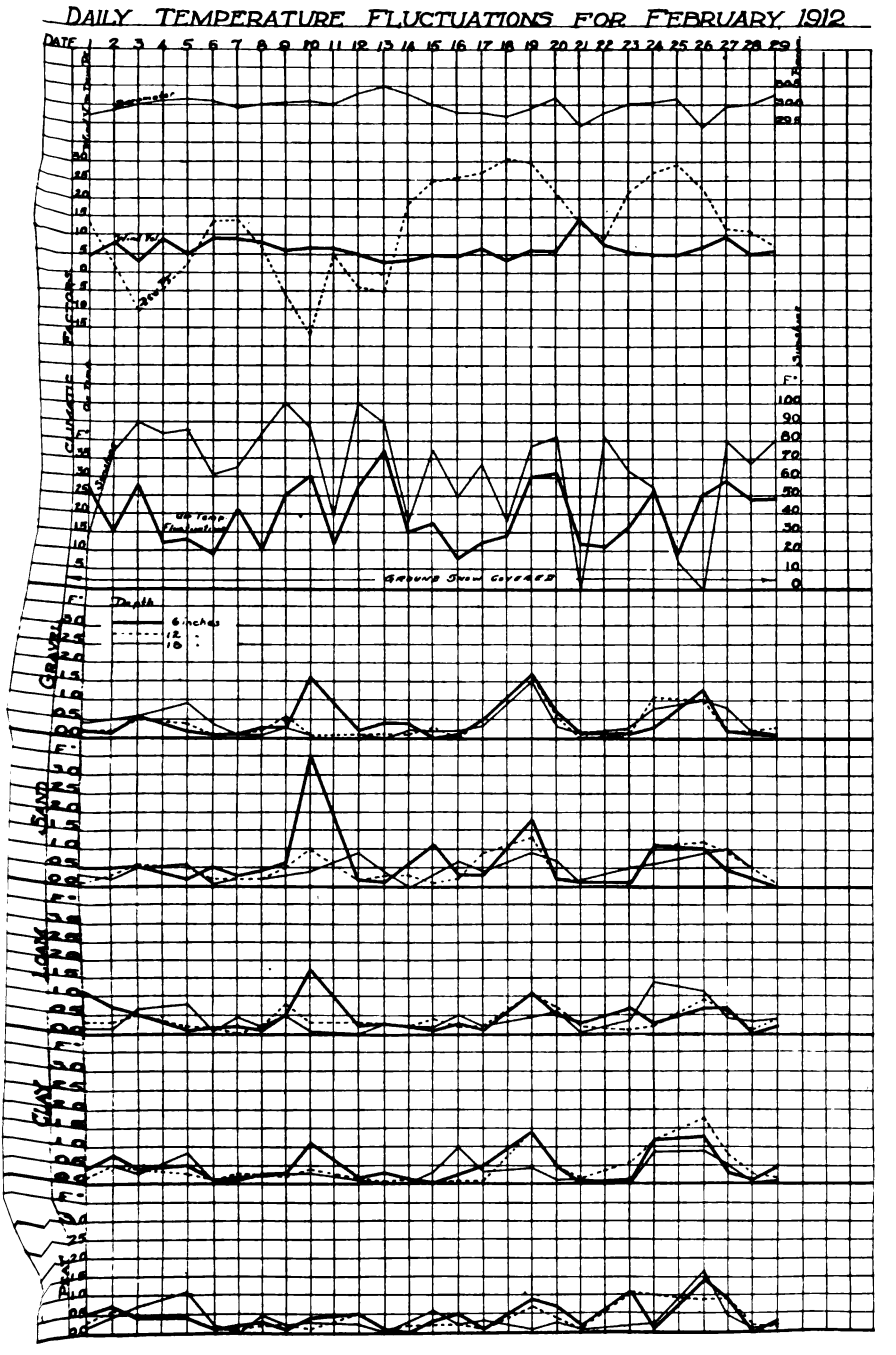


FIG. 18.

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TABLE 33.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, MARCH, 1912.

| Date - Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max... | 31.1 | 31.3 | 31.6 | 31.1 | 31.4 | 31.7 | 30. | 30.5 | 31.2 | 30.8 | 30.6 | 31.3 | 30.5 | 30.7 | 31.4 |
| 1 Min.... | 30.9 | 31.1 | 31.5 | 31.1 | 31.1 | 31.7 | 29.9 | 30.4 | 31. | 30.5 | 30.5 | 31.3 | 30.5 | 30.6 | 31.4 |
| 2 Max... | 31. | 31.3 | 31.4 | 31. | 31.5 | 31.9 | 30. | 30.5 | 31.4 | 30.5 | 31. | 31.8 | 30.4 | 30.9 | 31.8 |
| 2 Min.... | 30.9 | 31.2 | 31.3 | 31. | 31.4 | 31.8 | 29.9 | 30.5 | 31.2 | 30.4 | 30.9 | 31.3 | 30.3 | 30.7 | 31.7 |
| 4 Max... | 30.9 | 31.2 | 31.8 | 31. | 31.3 | 32. | 30. | 31. | 31.4 | 30.7 | 31.2 | 31.9 | 29.9 | 30.7 | 31.8 |
| 4 Min.... | 30.8 | 30.9 | 31.3 | 30.8 | 30.9 | 31.7 | 29.6 | 30.8 | 31.4 | 30.3 | 30.9 | 31.3 | 29.8 | 30.1 | 31.5 |
| 5 Max... | 30. | 30.8 | 31.5 | 30.7 | 31.1 | 31.9 | 29.8 | 30.9 | 31.5 | 30. | 30.9 | 31.8 | 29.8 | 30.5 | 31.4 |
| 5 Min.... | 29.9 | 30.4 | 31.2 | 30. | 31.1 | 31.9 | 29.1 | 30.8 | 30.9 | 29.4 | 30.9 | 31. | 28.8 | 30. | 31.3 |
| 6 Max... | 29.9 | 30.3 | 31.2 | 29.9 | 31.1 | 31.8 | 29. | 30. | 31. | 29.1 | 30. | 30.6 | 29. | 30. | 31.5 |
| 6 Min.... | 28.6 | 30. | 31.1 | 29.2 | 30.9 | 31.5 | 28.5 | 29.9 | 30.3 | 29.1 | 30. | 30.8 | 28.4 | 29.3 | 31. |
| 7 Max... | 29.2 | 30.3 | 31.6 | 30. | 31.2 | 32.1 | 29.2 | 30.5 | 31.8 | 30. | 30.6 | 31.4 | 28.9 | 30. | 31.6 |
| 7 Min.... | 28.9 | 29.9 | 31.4 | 29.3 | 30.9 | 32.1 | 28.9 | 30. | 31. | 29.5 | 30.3 | 31. | 27.3 | 29.7 | 31.1 |
| 8 Max... | 29.1 | 30. | 31.1 | 29.5 | 30.6 | 31.9 | 28.8 | 29.9 | 30.9 | 30. | 30.1 | 30.0 | 28.6 | 29.9 | 31.3 |
| 8 Min.... | 28.9 | 29.5 | 30.8 | 29.2 | 30. | 31. | 28.3 | 28.9 | 30. | 28.3 | 29.3 | 30.3 | 28.5 | 29. | 30.9 |
| 9 Max... | 29.9 | 30.4 | 31.1 | 30.1 | 30.9 | 31.5 | 29.2 | 30. | 30.9 | 29.4 | 30. | 30.3 | 29.2 | 29.4 | 31.2 |
| 9 Min.... | 29.8 | 30.3 | 31.1 | 30. | 30.6 | 31.2 | 29.1 | 30. | 30.6 | 29. | 29.8 | 30.2 | 28.5 | 29. | 31.2 |
| 11 Max... | 30.5 | 31.2 | 31.8 | 30.9 | 31.6 | 32. | 29.6 | 30.5 | 31.4 | 30. | 31. | 31.5 | 30. | 30. | 31.7 |
| 11 Min.... | 29.7 | 30.2 | 31.3 | 29.4 | 30.8 | 31.6 | 28.9 | 29.9 | 30.8 | 29.9 | 30.3 | 30.9 | 29.3 | 29.7 | 31.2 |
| 12 Max... | 29.8 | 30.2 | 31.1 | 29.9 | 30.8 | 31.4 | 29.4 | 30.1 | 30.8 | 30. | 30.3 | 30.9 | 29.4 | 30. | 31. |
| 12 Min.... | 29.4 | 30. | 31. | 29.3 | 30.7 | 31.2 | 29.1 | 29.9 | 30.3 | 29.3 | 29.9 | 30.4 | 29.2 | 29.8 | 30.9 |
| 13 Max... | 30.5 | 30.9 | 31.9 | 30.6 | 31. | 31.6 | 29.9 | 30.5 | 31.1 | 30.1 | 30.5 | 31.4 | 29.8 | 30.3 | 31.6 |
| 13 Min.... | 30. | 30.5 | 31.3 | 30. | 30.8 | 31.4 | 29.4 | 30. | 30.7 | 29.9 | 30.1 | 30.9 | 29.6 | 30. | 31.1 |
| 14 Max... | 29.9 | 30.1 | 31. | 29.6 | 30.4 | 31.3 | 29.3 | 30. | 30.9 | 29.8 | 30. | 30.6 | 29.4 | 29.9 | 30.9 |
| 14 Min.... | 29 3 | 29.6 | 30.1 | 29.1 | 30. | 30.9 | 28.8 | 29.3 | 30.1 | 28.9 | 29.5 | 30. | 28.3 | 28.5 | 29.9 |
| 15 Max... | 30.2 | 30.4 | 31.2 | 30. | 30.3 | 31.2 | 30. | 30.5 | 31.4 | 29.9 | 30.4 | 31.3 | 29.8 | 30.3 | 31. |
| 15 Min.... | 30.2 | 30.4 | 31.2 | 30. | 30.3 | 31.2 | 30. | 30.5 | 31.4 | 29.9 | 30.4 | 31.3 | 29.8 | 30.3 | 31. |
| 16 Max... | 30.5 | 30.9 | 31.5 | 30. | 30.5 | 31.6 | 30. | 30.3 | 30.9 | 30.3 | 31. | 31.3 | 29.9 | 30.4 | 31.3 |
| 16 Min.... | 29.5 | 29.9 | 30.6 | 29.7 | 30. | 31.1 | 29. | 29.6 | 30.3 | 29.9 | 30. | 30.4 | 29.4 | 29.5 | 30.4 |
| 18 Max... | 30.3 | 30.6 | 31. | 30.3 | 30.7 | 31.4 | 29.5 | 30.2 | 31. | 30. | 30.2 | 31. | 29.9 | 30. | 31.1 |
| 18 Min.... | 30.1 | 30.4 | 30.9 | 30.1 | 30.5 | 31.2 | 29.4 | 30. | 30.8 | 29.9 | 30.1 | 30.8 | 29.8 | 29.9 | 30.9 |
| 19 Max... | 30.7 | 30.9 | 31.2 | 30.8 | 31. | 31.7 | 29.8 | 30.2 | 31. | 30.2 | 30.5 | 30.8 | 30.1 | 30.1 | 31.2 |
| 19 Min.... | 30.1 | 30.5 | 30.9 | 30.3 | 30.7 | 31.3 | 29.5 | 29.9 | 30.7 | 29.9 | 30.2 | 30.5 | 29.9 | 29.9 | 31. |
| 21 Max... | 29.9 | 29.4 | 30.3 | 29.8 | 30.3 | 30.9 | 28.6 | 29.5 | 30. | 29. | 29.6 | 29.9 | 28.8 | 29.9 | 30.8 |
| 21 Min.... | 28.3 | 29. | 29.9 | 29. | 29.1 | 29.9 | 27.9 | 28.3 | 28.6 | 28.9 | 29.1 | 29.4 | 28.6 | 29. | 30. |
| 22 Max... | 29.4 | 29.8 | 30.6 | 30.2 | 31.2 | 31. | 29.2 | 30.1 | 29.9 | 29.5 | 30.1 | 30.6 | 30. | 30. | 30.3 |
| 22 Min.... | 27.8 | 28.8 | 30. | 29. | 29.7 | 29.9 | 28.1 | 28.9 | 29.1 | 29. | 29.6 | 29. | 28.8 | 29.6 | 30. |
| 23 Max... | 29.5 | 30.2 | 30.6 | 30. | 30.6 | 31.5 | 30. | 30.3 | 30.1 | 30.2 | 30.7 | 30.6 | 30.7 | 29.9 | 31.3 |
| 23 Min.... | 29.2 | 29.9 | 30. | 29.9 | 29.9 | 31. | 29.7 | 29.3 | 29.3 | 29.8 | 30.2 | 29.8 | 29.5 | 29.5 | 31. |
| 25 Max... | 30. | 30.4 | 31.4 | 30.3 | 31.3 | 31.8 | 29.9 | 30.8 | 31.5 | 30.1 | 30.6 | 31.4 | 30. | 30.2 | 31.7 |
| 25 Min.... | 29.4 | 30.1 | 31.3 | 30.3 | 31.1 | 31.1 | 29.5 | 30. | 30.9 | 29.8 | 30.2 | 30.6 | 29.8 | 29.5 | 31.2 |
| 26 Max... | 30.5 | 31.2 | 31.5 | 30.8 | 31.3 | 31.7 | 29.7 | 30.7 | 30.6 | 30. | 30.5 | 30.7 | 30. | 30.3 | 31.3 |
| 26 Min.... | 30.2 | 30.8 | 31.2 | 30.6 | 29.9 | 31.5 | 29.3 | 30. | 30.2 | 29.8 | 29.9 | 30.2 | 29.8 | 30. | 31. |
| 27 Max... | 30.5 | 30.9 | 31.3 | 30.8 | 31.1 | 32.1 | 31.3 | 30.8 | 31.5 | 30.7 | 30.9 | 31.2 | 30.1 | 30.5 | 31.7 |
| 27 Min.... | 29.7 | 30.4 | 30.8 | 29.3 | 30.2 | 31. | 29.4 | 30.3 | 30.8 | 30.5 | 30.5 | 30.9 | 29.9 | 30.4 | 31.3 |
| 28 Max... | 30.8 | 31.2 | 31.2 | 30.6 | 31.2 | 32. | 30.4 | 31. | 31. | 30.7 | 30.8 | 31. | 29.9 | 30.8 | 31.9 |
| 28 Min.... | 30. | 30.6 | 30.3 | 30. | 30.4 | 31. | 29.4 | 30. | 30.3 | 30.3 | 30.3 | 30.7 | 29.8 | 30.4 | 31.2 |
| 29 Max... | 31.6 | 31.6 | 31.4 | 31.2 | 31.3 | 31.8 | 30.8 | 31.2 | 31.3 | 30.7 | 31.7 | 32. | 30.7 | 30.3 | 31.1 |
| 29 Min.... | 28.8 | 28.2 | 29. | 28.3 | 29. | 29.1 | 28.5 | 28.8 | 29.5 | 29.5 | 30. | 30.1 | 29.6 | 29.8 | 30.7 |
| 30 Max... | 30.4 | 30.9 | 30.9 | 30.9 | 30.9 | 32.1 | 30.7 | 30.8 | 30.9 | 30.8 | 31.1 | 31. | 30.8 | 30.8 | 31.9 |
| 30 Min.... | 30.2 | 30.6 | 30.8 | 30.8 | 30.7 | 31.8 | 30.2 | 29.9 | 30.7 | 29.6 | 30.7 | 31. | 30.7 | 30.3 | 30.1 |
| Monthly range.... | 0.58 | 0.53 | 0.44 | 0.57 | 0.57 | 0.51 | 0.59 | 0.57 | 0.56 | 0.43 | 0.43 | 0.84 | 0.47 | 0.48 | 0.43 |

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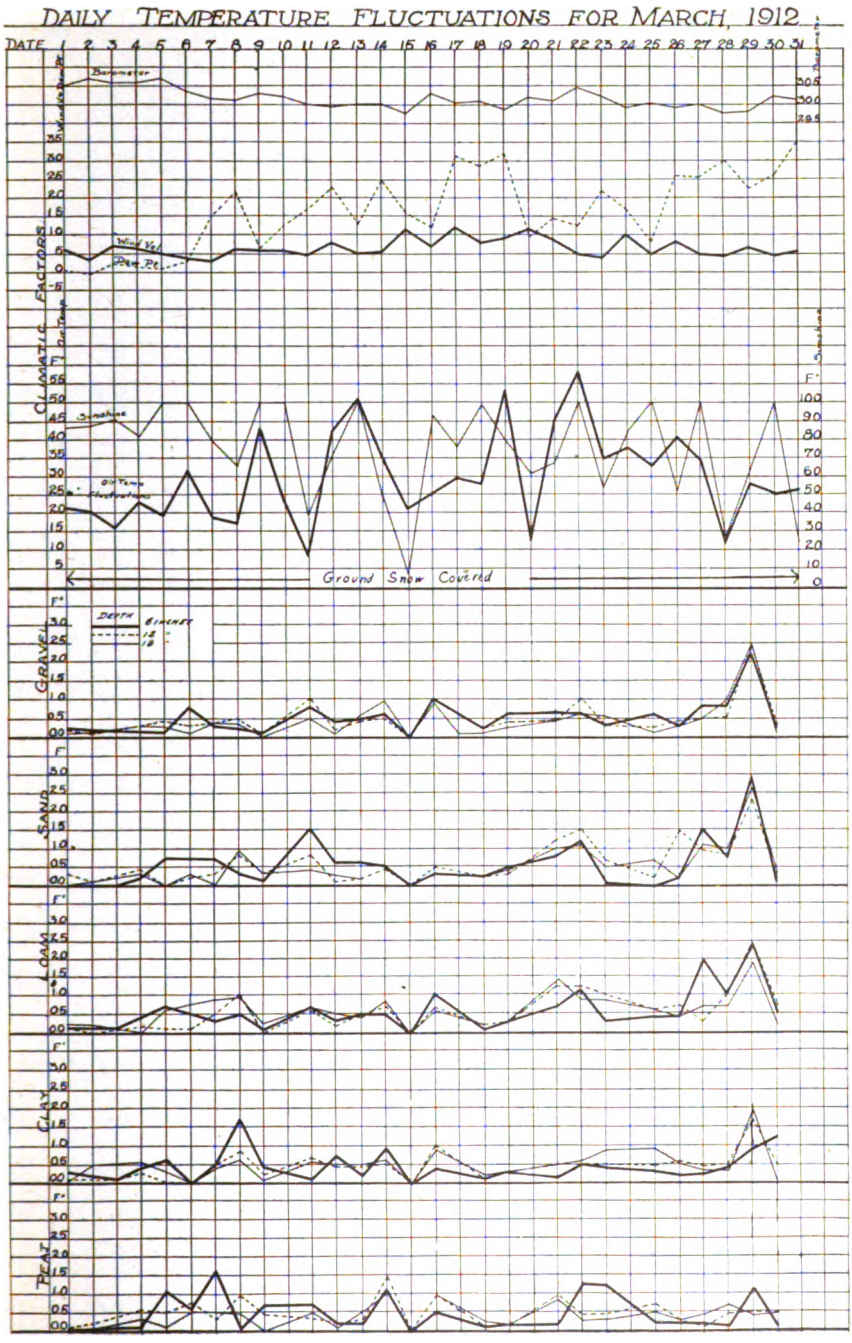


FIG. 19.

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TABLE 34.—DAILY MAXIMUM AND MINIMUM TEMPERATURES OF DIFFERENT TYPES OF SOIL, APRIL, 1912.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 32.1 | 31.9 | 31.7 | 31.5 | 31.9 | 31.9 | 31.2 | 31.5 | 31.9 | 32. | 31.7 | 31.8 | 31.5 | 31.6 | 31.9 |
| 1 Min. | 31.7 | 31.7 | 31.4 | 31.2 | 31.6 | 31.7 | 30.9 | 31.4 | 31.7 | 41.4 | 31.4 | 31.6 | 31.4 | 31.2 | 31.6 |
| 2 Max. | 31. | 31.2 | 31.2 | 31.3 | 31.3 | 31.3 | 31. | 31.2 | 31.2 | 31. | 31.4 | 31.3 | 31.1 | 31.1 | 31.3 |
| 2 Min. | 30.9 | 30.8 | 30.8 | 30.9 | 30.9 | 30.9 | 30. | 30.3 | 30.8 | 30.8 | 30.7 | 30.5 | 30.5 | 30. | 30.6 |
| 3 Max. | 30.6 | 30.9 | 30.6 | 30.5 | 30.8 | 31. | 31. | 31. | 31.2 | 31. | 31.1 | 31.1 | 30.8 | 30.3 | 31. |
| 3 Min. | 29.2 | 29.5 | 29. | 29.4 | 29.3 | 30.1 | 29.8 | 30.8 | 31. | 30.8 | 30.9 | 31. | 30.8 | 29.4 | 30.4 |
| 4 Max. | 32. | 31.1 | 30.9 | 30.9 | 31. | 31.3 | 30.9 | 30.8 | 31. | 30.8 | 30.8 | 30.9 | 30.5 | 30. | 30.5 |
| 4 Min. | 30.8 | 30. | 30. | 29.9 | 30.1 | 30.9 | 29. | 29.2 | 29.9 | 30.1 | 30. | 30. | 29.4 | 29.1 | 29.4 |
| 5 Max. | 33.6 | 34.1 | 31.3 | 30.6 | 31. | 31.4 | 30.2 | 30.6 | 31. | 33.9 | 31. | 31.1 | 30.7 | 30.4 | 31.1 |
| 5 Min. | 32.5 | 31.1 | 31.1 | 30.9 | 30.9 | 31.4 | 30.2 | 30.3 | 30.9 | 30. | 30.8 | 30.7 | 30.4 | 29.9 | 31. |
| 6 Max. | 44.5 | 46. | 32.8 | 43.9 | 30.8 | 32.3 | 31.9 | 30.4 | 31. | 36.2 | 31. | 31. | 30.5 | 30.1 | 31.2 |
| 6 Min. | 37.5 | 34.5 | 31.2 | 34.8 | 31.1 | 31.4 | 30.1 | 30.1 | 30.8 | 33.9 | 30.8 | 30.8 | 30.3 | 29.9 | 31. |
| 7 Max. | 41.7 | 41. | 37.1 | 37.9 | 37. | 34.6 | 32.7 | 30.3 | 31. | 37.5 | 31. | 31. | 30.6 | 30.2 | 31. |
| 7 Min. | 38.8 | 38.9 | 36.9 | 36.1 | 35.6 | 34.5 | 32.2 | 30.1 | 30.8 | 35.2 | 30.6 | 30.5 | 30.3 | 30. | 30.9 |
| 8 Max. | 40. | 37.3 | 35. | 33.7 | 33.1 | 34.1 | 33.1 | 30.6 | 31. | 35.8 | 31.1 | 31. | 30.8 | 30.5 | 31.2 |
| 8 Min. | 33.5 | 34.7 | 35. | 32.2 | 33.1 | 33.5 | 31. | 30.2 | 30.9 | 31.9 | 30.7 | 30.5 | 30.5 | 30.1 | 31.1 |
| 9 Max. | 44.8 | 49.8 | 36.5 | 45.7 | 46. | 35.8 | 36. | 30.4 | 31.1 | 39.5 | 31.3 | 30.9 | 30.9 | 30.5 | 31.1 |
| 9 Min. | 37. | 37.2 | 35.6 | 36. | 36. | 34.9 | 33. | 30.3 | 30.9 | 35. | 31. | 30.9 | 30.6 | 30.4 | 31. |
| 10 Max. | 47. | 42.8 | 38.1 | 48. | 42.8 | 38. | 37.8 | 30.6 | 31.1 | 41. | 33. | 31.1 | 30.8 | 30.4 | 31.2 |
| 10 Min. | 38.6 | 39.2 | 37.6 | 38. | 38.3 | 37. | 33.8 | 30.3 | 30.7 | 36.6 | 32. | 30.9 | 30.4 | 30.3 | 31. |
| 11 Max. | 50.5 | 45. | 39.5 | 50.5 | 44.1 | 39. | 39.8 | 30.6 | 31. | 43.9 | 34.5 | 30.9 | 30.9 | 30.2 | 31.1 |
| 11 Min. | 41. | 41. | 38.5 | 40.2 | 39.9 | 38. | 35.1 | 30.3 | 30.9 | 37.1 | 33.3 | 30.8 | 30.5 | 30.1 | 31. |
| 12 Max. | 49. | 45.4 | 41.5 | 48.5 | 44.5 | 40.1 | 40. | 31.7 | 31. | 44.8 | 38.5 | 35.2 | 30.7 | 30.2 | 31. |
| 12 Min. | 45. | 43.9 | 41. | 44. | 42.8 | 39.9 | 38.1 | 31.2 | 30.9 | 42. | 37. | 33. | 30.5 | 30.1 | 30.8 |
| 13 Max. | 47. | 44.8 | 41.6 | 46.6 | 43.9 | 41. | 39.4 | 33. | 31.2 | 44.5 | 40. | 38.1 | 30.9 | 30.2 | 31. |
| 13 Min. | 44. | 43.6 | 41.5 | 43.1 | 42.5 | 40.4 | 38. | 32.9 | 31. | 42.4 | 39.8 | 37.1 | 30.5 | 30.1 | 30.9 |
| 15 Max. | 51.5 | 49. | 44. | 52. | 47.3 | 43. | 45.7 | 39.8 | 37.1 | 49.5 | 44. | 41.3 | 34.3 | 31. | 31.5 |
| 15 Min. | 42. | 42. | 39.2 | 40.8 | 40.3 | 38.1 | 37.9 | 34. | 33. | 41.4 | 38.3 | 36.4 | 31.8 | 30. | 31. |
| 16 Max. | 48. | 46.8 | 44.3 | 48.1 | 46. | 43.8 | 45.2 | 42.2 | 39. | 47.7 | 44.2 | 42.2 | 34. | 30.9 | 31.6 |
| 16 Min. | 45.5 | 44.8 | 42.5 | 44.5 | 43.2 | 42. | 42.9 | 41.1 | 38.2 | 45. | 43. | 41. | 33. | 30. | 30.6 |
| 17 Max. | 44.5 | 43.8 | 43.5 | 44. | 43.2 | 42.6 | 42.9 | 42.4 | 40.5 | 44.3 | 43.8 | 42.2 | 34.1 | 30.3 | 31.4 |
| 17 Min. | 42.5 | 43.1 | 42.8 | 41.5 | 42. | 42. | 42.2 | 42. | 40.1 | 43.5 | 42.8 | 41.9 | 33.9 | 30.2 | 31.1 |
| 18 Max. | 41.5 | 41.8 | 42.2 | 41. | 40.8 | 41 | 40.7 | 41.5 | 40.6 | 41.3 | 42.4 | 41.5 | 33.6 | 30.6 | 31.6 |
| 18 Min. | 40.1 | 41.2 | 41.8 | 39.4 | 40. | 40.2 | 40.2 | 41.1 | 40.2 | 41. | 41.1 | 41.1 | 33.5 | 30.5 | 31.5 |
| 19 Max. | 45. | 43.1 | 40.9 | 45.2 | 43. | 42.0 | 42.3 | 40. | 40. | 44.5 | 40. | 40.1 | 33.6 | 30.5 | 31.8 |
| 19 Min. | 37.4 | 39.1 | 40. | 36.5 | 38.5 | 39.9 | 38.1 | 40. | 39.8 | 38.5 | 39.9 | 40.1 | 32.8 | 30.2 | 31.6 |
| 20 Max. | 39.6 | 40.7 | 42. | 40.3 | 39.8 | 41.5 | 44. | 41. | 42. | 41. | 43.1 | 40.4 | 36. | 30.6 | 32.4 |
| 20 Min. | 38.1 | 36.7 | 38. | 38.7 | 38.9 | 39. | 38.4 | 38.2 | 38. | 38. | 37.4 | 37.5 | 32. | 29.6 | 31. |
| 22 Max. | 48.2 | 47.1 | 44.4 | 47.7 | 46.9 | 44.4 | 47.8 | 44.8 | 41.8 | 48.2 | 44.6 | 43.5 | 36.4 | 30.9 | 31.9 |
| 22 Min. | 46. | 46. | 44.3 | 45.3 | 45.5 | 44. | 46.9 | 44.6 | 41.8 | 46.9 | 44.6 | 43.2 | 38.9 | 30.6 | 31 8 |
| 23 Max. | 47.2 | 44.8 | 43.1 | 49. | 44.9 | 43.8 | 44.4 | 43.9 | 42.7 | 45.1 | 43.5 | 43. | 36.6 | 30.7 | 32. |
| 23 Min. | 39.8 | 41.3 | 42.1 | 39.1 | 40.6 | 41.9 | 41.2 | 42.2 | 41.3 | 41.3 | 42.2 | 41.5 | 35.5 | 30.3 | 31.8 |
| 24 Max. | 51.7 | 47.9 | 43.6 | 52.1 | 47.5 | 43.5 | 48.1 | 43.6 | 41.9 | 49. | 44. | 42.5 | 39. | 30.5 | 32. |
| 24 Min. | 44.5 | 44.9 | 43.1 | 44.8 | 44.3 | 42.8 | 45. | 43.5 | 41.6 | 44.9 | 43.4 | 42.2 | 38. | 30.3 | 32. |
| 25 Max. | 52. | 48.4 | 44.4 | 53. | 47.6 | 44.2 | 49. | 44.9 | 42.5 | 49.6 | 44.8 | 43.3 | 39.2 | 30.8 | 32.1 |
| 25 Min. | 43.4 | 44.7 | 43.8 | 42.5 | 43.7 | 43.1 | 45.3 | 44. | 42.1 | 44.9 | 44.5 | 43.1 | 38.3 | 30.2 | 32. |
| 26 Max. | 53.7 | 49.9 | 46.9 | 54.3 | 49.5 | 45.5 | 50.8 | 47.2 | 44.2 | 51.8 | 46.5 | 45.5 | 42. | 31. | 33.1 |
| 26 Min. | 48.7 | 47.6 | 45. | 48.9 | 46.5 | 44.8 | 48.6 | 46.1 | 43.3 | 48.7 | 46. | 44.4 | 41.3 | 30.5 | 32.2 |
| 27 Max. | 54.6 | 51. | 49.8 | 55.2 | 50.3 | 48.7 | 52.1 | 47.9 | 45. | 55.5 | 47.8 | 45.9 | 43.8 | 31. | 33.1 |
| 27 Min. | 48.2 | 48.2 | 46.4 | 48. | 48. | 46.5 | 49.2 | 47.6 | 44.2 | 49.4 | 47.2 | 45.3 | 42.8 | 30.9 | 32.9 |
| 29 Max. | 44. | 43.8 | 44.5 | 43.6 | 43.5 | 44.5 | 44.8 | 46. | 45. | 44. | 45.2 | 45.1 | 40.7 | 31.5 | 34.1 |
| 29 Min. | 42.8 | 43.2 | 43.9 | 42. | 43. | 43.2 | 44. | 44.5 | 44.2 | 43.5 | 44. | 44. | 39.9 | 31.4 | 34. |
| 30 Max. | 50.1 | 48.5 | 43. | 52.6 | 46.6 | 43. | 46. | 44. | 43.6 | 47.0 | 43.3 | 43.9 | 30.5 | 31.5 | 34.9 |
| 30 Min. | 39. | 41. | 42.3 | 38.7 | 41. | 42.3 | 41.5 | 43. | 43. | 41. | 42.8 | 43. | 38. | 31.4 | 34.1 |
| Monthly range. | 4.93 | 2.66 | 0.66 | 5.44 | 2.59 | 0.93 | 2.47 | 0.84 | 0.66 | 3.25 | 1.23 | 0.85 | 0.76 | 0.39 | 0.18 |

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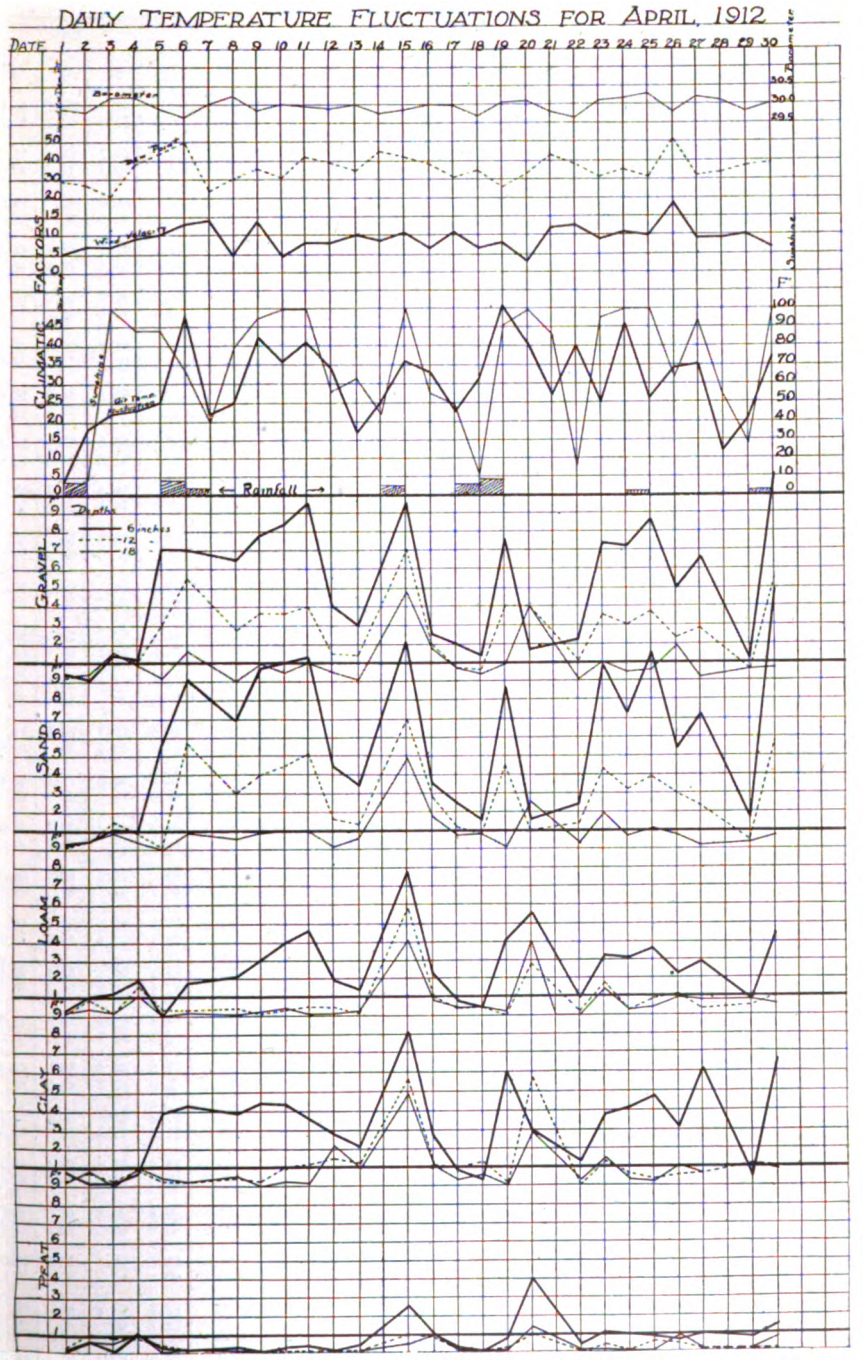


FIG. 20.

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TABLE 35.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, MAY, 1912.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max... | 46.9 | 45.9 | 44.8 | 47.4 | 45.9 | 44.7 | 45.2 | 44.6 | 43.5 | 46.2 | 44.9 | 44. | 42.1 | 33.2 | 35.9 |
| 1 Min.... | 44.9 | 44.9 | 44.4 | 44.9 | 44.9 | 44.4 | 44.8 | 44.5 | 43.1 | 44.9 | 44.5 | 43.9 | 41.9 | 32.3 | 35.5 |
| 2 Max... | 54. | 49.8 | 45. | 55. | 45.3 | 45.2 | 46.3 | 45. | 43.9 | 51.5 | 45.9 | 44.4 | 44.2 | 35. | 37.1 |
| 2 Min.... | 44.3 | 44.7 | 44.2 | 44. | 44.9 | 44.2 | 45. | 44.4 | 43.5 | 45.1 | 44.4 | 44.1 | 42.1 | 34.4 | 36.9 |
| 3 Max... | 58. | 53. | 47.2 | 58.8 | 53. | 47.1 | 53. | 48. | 44.9 | 55.9 | 48.5 | 46. | 48.0 | 40. | 40.8 |
| 3 Min.... | 49.2 | 49. | 46.4 | 48.9 | 48.4 | 46.3 | 49. | 46. | 44.4 | 49.9 | 47. | 45.4 | 46.6 | 38. | 38.9 |
| 4 Max... | 59.9 | 55. | 48.8 | 60.4 | 55.6 | 49. | 56. | 49.5 | 46.3 | 58. | 50. | 48.6 | 52.2 | 45.4 | 43.4 |
| 4 Min.... | 51.4 | 51. | 48. | 51. | 50.3 | 47.4 | 51.6 | 49. | 45.8 | 52.4 | 49.5 | 47.2 | 50.4 | 43.8 | 42.3 |
| 6 Max... | 63. | 57.5 | 51.3 | 63.5 | 57.2 | 51.3 | 56. | 52.8 | 46.9 | 61. | 53. | 50.3 | 56.9 | 50.4 | 47.6 |
| 6 Min.... | 53.2 | 53. | 50.2 | 52.4 | 52.1 | 50. | 53. | 51.8 | 48. | 54.4 | 52. | 49.7 | 54.8 | 49. | 46.4 |
| 7 Max... | 63.5 | 60.5 | 53. | 63.8 | 59. | 52.5 | 61. | 54.9 | 49.9 | 62.8 | 55. | 52. | 56.8 | 52.1 | 48.8 |
| 7 Min.... | 56.8 | 56.1 | 52.3 | 56.4 | 55.7 | 52. | 58. | 54.2 | 49.8 | 58.2 | 54.4 | 51.7 | 58. | 52. | 48.4 |
| 8 Max... | 59.8 | 57.4 | 53.4 | 60. | 56.7 | 52.8 | 58.4 | 55.4 | 51.2 | 59.5 | 55.5 | 53. | 56.8 | 54.5 | 50.4 |
| 8 Min.... | 55. | 55. | 52.8 | 54. | 54. | 52.4 | 56.9 | 55. | 50.8 | 57.1 | 54.4 | 52.8 | 50. | 53.8 | 49.5 |
| 9 Max... | 59.3 | 55.8 | 53. | 60.2 | 55.5 | 52.5 | 56.2 | 54.8 | 51.7 | 58. | 55. | 53.1 | 56.5 | 55. | 51.8 |
| 9 Min.... | 51.5 | 53. | 51.8 | 50. | 52.1 | 51.2 | 54. | 53.2 | 50.8 | 54.3 | 53.8 | 52. | 57.3 | 54. | 51.4 |
| 10 Max... | 63. | 58. | 52.4 | 64.5 | 56. | 52.2 | 59. | 53.5 | 51. | 60.9 | 54. | 52. | 58.4 | 54.5 | 52. |
| 10 Min.... | 51. | 52.8 | 52. | 50.5 | 52. | 51.5 | 54. | 53.3 | 50.5 | 53.9 | 53.5 | 52. | 56.8 | 54.3 | 51.2 |
| 11 Max... | 57.4 | 57. | 53.5 | 56.5 | 56. | 53.5 | 58. | 55.2 | 51. | 58.2 | 55.8 | 53. | 56.9 | 55. | 52. |
| 11 Min.... | 55.5 | 54.9 | 52.2 | 55. | 54.3 | 52. | 56. | 54. | 50.4 | 56.1 | 54. | 52. | 57.9 | 54.8 | 51.5 |
| 13 Max... | 51.3 | 49.5 | 49. | 53. | 50. | 49. | 49.9 | 50.4 | 50.2 | 50.5 | 50. | 50.6 | 51. | 54. | 53. |
| 13 Min.... | 43. | 45.8 | 48.3 | 43.5 | 46.4 | 48.6 | 47.4 | 49.5 | 49.9 | 46. | 49. | 50.5 | 50.3 | 53. | 52.6 |
| 14 Max... | 54. | 51.7 | 49.4 | 56. | 52.5 | 49.6 | 51.8 | 50. | 49.2 | 53.8 | 50.3 | 49.8 | 52.2 | 52. | 52. |
| 14 Min.... | 45.9 | 46.9 | 47.5 | 46. | 47.5 | 48.4 | 47.2 | 48.4 | 48. | 47.8 | 48.3 | 48.5 | 50.1 | 51.2 | 51. |
| 15 Max... | 48.8 | 48.4 | 49. | 48.4 | 48.5 | 50.1 | 48.9 | 50. | 49.1 | 49.9 | 50.4 | 50. | 51.5 | 51.7 | 51.5 |
| 15 Min.... | 47. | 48. | 48.5 | 46.2 | 48. | 49. | 48. | 49. | 48.9 | 49. | 49.5 | 49.5 | 50. | 51. | 51. |
| 16 Max... | 49.4 | 48.3 | 48.1 | 49.5 | 48.2 | 48.8 | 48.8 | 48.7 | 48.5 | 49.8 | 49.2 | 49.9 | 49.7 | 50.5 | 51. |
| 16 Min.... | 47. | 47.8 | 48. | 47. | 47.8 | 48.4 | 48. | 48.6 | 48.4 | 48.2 | 48.5 | 48.8 | 49.3 | 50. | 50.4 |
| 17 Max... | 54. | 51. | 48. | 49.5 | 51. | 48. | 50.3 | 46.2 | 47.9 | 52.5 | 48.3 | 48.4 | 49.5 | 49.5 | 49.8 |
| 17 Min.... | 46.8 | 47. | 47.1 | 45.8 | 46.9 | 47. | 47.2 | 47.9 | 47.2 | 47.7 | 47.8 | 47.9 | 48.4 | 48.9 | 49. |
| 18 Max... | 50.4 | 48.6 | 48.5 | 52.8 | 49.1 | 48. | 50.2 | 48.9 | 47.4 | 49.8 | 48.7 | 48.2 | 49.4 | 49.1 | 49.5 |
| 18 Min.... | 45.8 | 47.2 | 47.2 | 46.5 | 48.5 | 47.6 | 48.2 | 47.8 | 46.8 | 48.5 | 48.5 | 48.1 | 49. | 48.2 | 48.6 |
| 20 Max... | 55.1 | 53. | 50. | 55.4 | 52.6 | 50. | 52.6 | 50. | 49.3 | 54.4 | 51.3 | 50. | 52.6 | 56.2 | 49.6 |
| 20 Min.... | 49.5 | 49.9 | 49.5 | 49.2 | 49.5 | 49.7 | 50. | 49.9 | 48.8 | 50.9 | 50.5 | 49.4 | 51. | 49.2 | 48.9 |
| 21 Max... | 59.5 | 56.3 | 52. | 59.8 | 55.8 | 51.8 | 56.4 | 52. | 50. | 58. | 52.9 | 51.8 | 55.1 | 53.5 | 50. |
| 21 Min.... | 52.4 | 51.7 | 49.5 | 51.9 | 51. | 49.5 | 51.9 | 50.1 | 48.2 | 52.6 | 50.5 | 49.5 | 52.4 | 49.5 | 48.8 |
| 22 Max... | 64.2 | 59.6 | 53.7 | 67.9 | 60.1 | 53.7 | 59.8 | 54. | 50.9 | 62.2 | 55. | 52.5 | 58.1 | 52.9 | 50.8 |
| 22 Min.... | 56. | 55.2 | 52.7 | 55.5 | 54.5 | 52.8 | 56. | 53.2 | 50.7 | 56.4 | 54. | 52.4 | 56.3 | 52.3 | 50.7 |
| 23 Max... | 69.6 | 63.7 | 56. | 71.7 | 63.7 | 58.1 | 63.5 | 56.4 | 52.4 | 67. | 58. | 54.8 | 61.8 | 55. | 51.9 |
| 23 Min.... | 60.3 | 59.1 | 55.2 | 60.8 | 59. | 55.4 | 59.8 | 55.9 | 52. | 61.1 | 57.2 | 54.1 | 60.3 | 52. | 51.5 |
| 24 Max... | 67.5 | 63.7 | 58.7 | 68.6 | 63.5 | 57.9 | 64.2 | 59.4 | 54.5 | 66.9 | 60.8 | 57.2 | 64.0 | 58.7 | 53.3 |
| 24 Min.... | 64.0 | 62.2 | 58.1 | 63.2 | 61.4 | 57.3 | 63.2 | 59. | 54. | 64.4 | 59.7 | 56.8 | 63.7 | 56.9 | 53. |
| 25 Max... | 69.6 | 63.9 | 57.8 | 71.3 | 63.5 | 57.5 | 64. | 59.3 | 55.7 | 67.1 | 60.2 | 57.3 | 63.7 | 58.8 | 55.3 |
| 25 Min ... | 58.7 | 59.3 | 57. | 57. | 58.2 | 56.9 | 60.3 | 58.5 | 55. | 61.1 | 59.3 | 57.1 | 62.4 | 58.4 | 54.5 |
| 27 Max... | 67.3 | 64.3 | 60.2 | 67.7 | 63.3 | 59.9 | 65.5 | 61.9 | 57.1 | 66.8 | 62.6 | 59.3 | 66.4 | 60.9 | 57.1 |
| 27 Min.... | 64.4 | 63. | 59.8 | 64. | 61.9 | 59.2 | 64.3 | 61.3 | 56.9 | 64.9 | 61.9 | 59.2 | 65.5 | 60.8 | 56.5 |
| 28 Max... | 64.5 | 63. | 59.9 | 64.2 | 62.3 | 59.8 | 64.9 | 61.8 | 57.9 | 65.2 | 62.3 | 59.6 | 66.6 | 62. | 58.3 |
| 28 Min.... | 63.9 | 62.6 | 59.5 | 63.5 | 61.8 | 59.2 | 64. | 61.3 | 57.8 | 64.4 | 61.9 | 59.6 | 66. | 61.6 | 57.9 |
| 29 Max... | 60.2 | 60.7 | 59.5 | 59.3 | 60. | 59.1 | 62.3 | 61.5 | 58.2 | 62.1 | 61.4 | 59.8 | 65. | 62.5 | 59.2 |
| 29 Min.... | 58.8 | 58.9 | 58. | 58. | 58. | 58. | 60.1 | 60.1 | 57.9 | 59.8 | 59.8 | 59. | 63. | 62.1 | 59.1 |
| 30 Max... | 66. | 61.3 | 56.7 | 66.8 | 62. | 58.8 | 61.3 | 58.3 | 57.1 | 63.4 | 56. | 57.9 | 61.8 | 61. | 58.1 |
| 30 Min.... | 54.5 | 55.9 | 56. | 53.5 | 55.1 | 56. | 57. | 57.3 | 56.3 | 56.3 | 57. | 56.7 | 60. | 60. | 58.7 |
| 31 Max... | 70.4 | 64.3 | 58. | 72. | 64.3 | 58.2 | 64.3 | 59. | 56.9 | 67. | 58.6 | 58.2 | 63.1 | 61. | 58.3 |
| 31 Min.... | 58.8 | 59.3 | 58. | 58. | 59.5 | 58.1 | 60.3 | 58.6 | 56.3 | 60.3 | 59.4 | 57.5 | 61.8 | 60. | 58.1 |
| Monthly range... | 6.59 | 3.18 | 0.63 | 7.76 | 3.28 | 0.47 | 2.92 | 0.78 | 0.52 | 4.14 | 0.97 | 0.59 | 1.81 | 0.98 | 0.62 |

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DAILY TEMPERATURE FLUCTUATIONS FOR MAY —— 1912

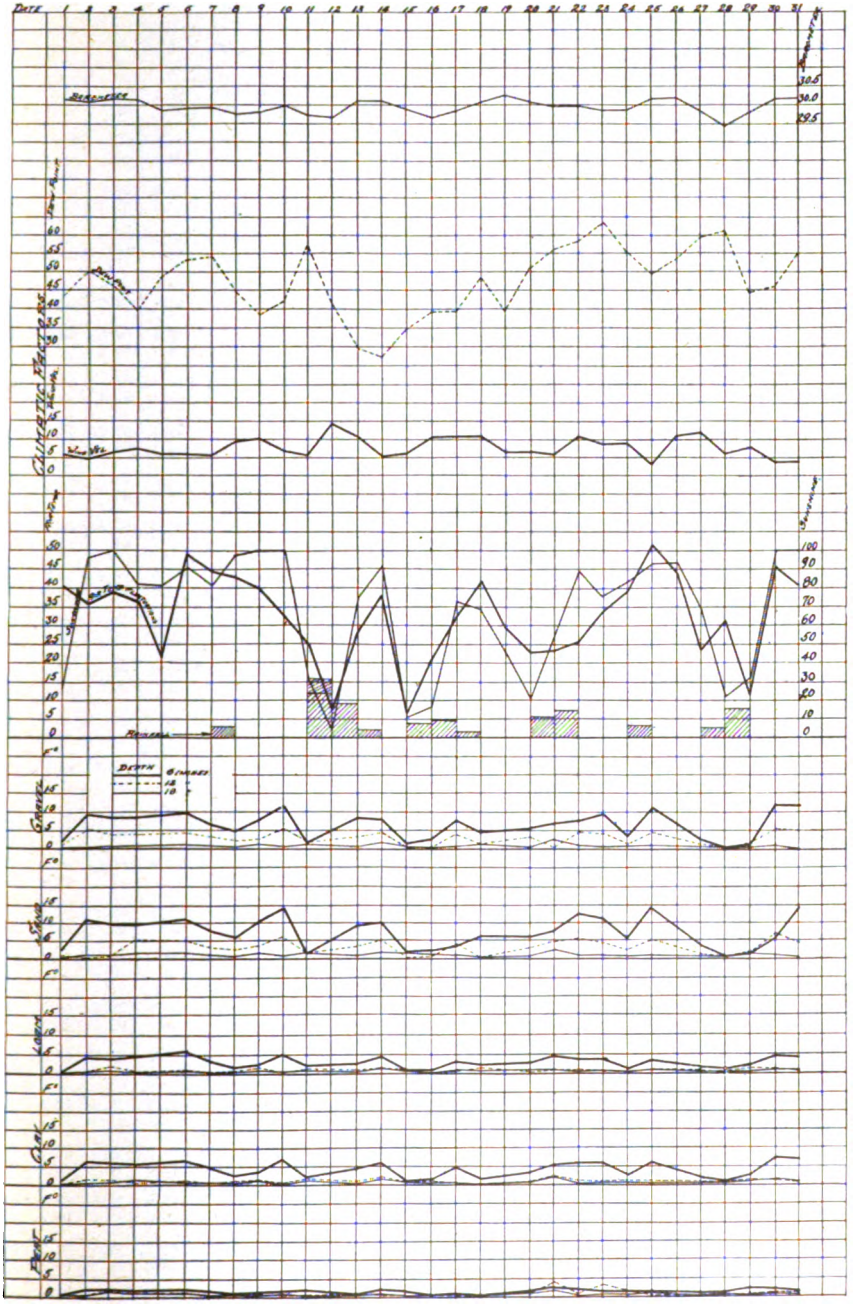


FIG. 21.



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TABLE 36.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, JUNE, 1912.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 72.8 | 67. | 60. | 73.7 | 66.1 | 60. | 65. | 61.9 | 57.3 | 69.8 | 62.3 | 59.8 | 67. | 61.5 | 58.8 |
| 1 Min. | 63.8 | 62.8 | 59.3 | 61.9 | 61.9 | 59. | 61.8 | 60.5 | 57. | 63.9 | 61. | 59. | 64.4 | 60.6 | 58. |
| 3 Max. | 70.5 | 65.7 | 60.3 | 71.6 | 65.1 | 59.9 | 60.1 | 61.9 | 59. | 68.1 | 62. | 60.2 | 65.9 | 62.3 | 59.8 |
| 3 Min. | 59.9 | 60.5 | 59.1 | 58.8 | 59.9 | 59. | 62. | 60 9 | 58.3 | 61.8 | 61. | 60. | 64. | 62. | 59.1 |
| 4 Max. | 66.9 | 63.8 | 61. | 60. | 64. | 60.6 | 64.4 | 62.8 | 59. | 66. | 62.8 | 60.6 | 66.8 | 62.8 | 60. |
| 4 Min. | 62.8 | 62.3 | 60.3 | 61.2 | 61.3 | 60. | 63.4 | 62. | 58.9 | 63.9 | 62.1 | 60.5 | 65.9 | 62.8 | 59.8 |
| 5 Max. | 66.8 | 62.7 | 60.1 | 67.5 | 62.8 | 59.9 | 63. | 61.4 | 59.1 | 65. | 61.9 | 60.4 | 64.8 | 62.9 | 60.4 |
| 5 Min. | 57.9 | 59.4 | 59. | 56.5 | 58.6 | 58.7 | 60. | 60. | 58.3 | 60.3 | 60.3 | 59.5 | 63. | 62.8 | 60. |
| 6 Max. | 70. | 65.5 | 60.1 | 70. | 65.3 | 60.1 | 65.8 | 61. | 58.4 | 67.7 | 61.8 | 59.9 | 65.4 | 62.2 | 60.1 |
| 6 Min. | 62.3 | 62. | 59.9 | 61.7 | 61.3 | 59.7 | 62.3 | 60.9 | 58.3 | 63. | 61.1 | 59.8 | 64.2 | 62. | 60. |
| 7 Max. | 68.6 | 64.1 | 61. | 68.8 | 63.7 | 60.3 | 64.3 | 62. | 59. | 66.7 | 62.2 | 60.5 | 64.8 | 62.3 | 60.3 |
| 7 Min. | 60. | 60.8 | 59.9 | 58.2 | 59.9 | 59.3 | 61.2 | 60.70 | 58.6 | 61.9 | 61.9 | 59.9 | 63.1 | 62. | 60. |
| 8 Max. | 66. | 64.4 | 60.5 | 67.8 | 63.4 | 59.9 | 64.3 | 61.5 | 58.9 | 65.9 | 61.8 | 60.1 | 64. | 62.1 | 60.2 |
| 8 Min. | 59.2 | 60.4 | 59.5 | 57.6 | 59.6 | 59. | 60.7 | 60.4 | 58.5 | 61. | 60.4 | 59.8 | 62.4 | 61.8 | 60. |
| 10 Max. | 71.2 | 66.1 | 61.2 | 71.7 | 65.7 | 60.9 | 60.8 | 62.1 | 59.1 | 66.4 | 62.4 | 61.3 | 65.7 | 62.8 | 60.7 |
| 10 Min. | 61.6 | 61.9 | 60.3 | 60. | 60.9 | 59.9 | 62.6 | 61.3 | 58.9 | 63.1 | 61.3 | 60.1 | 63.7 | 61.8 | 59.9 |
| 11 Max. | 71.2 | 66.3 | 62. | 71.2 | 65.7 | 61.4 | 67.1 | 63. | 59.9 | 68.2 | 63. | 61.3 | 66. | 62.4 | 60.1 |
| 11 Min. | 62.8 | 62.8 | 60.9 | 61.4 | 61.9 | 60.3 | 63.5 | 62.0 | 59.3 | 61.9 | 62.1 | 60.5 | 64.3 | 62.2 | 60.0 |
| 12 Max. | 72. | 67.6 | 62.5 | 71.7 | 66.5 | 62.3 | 66.6 | 64. | 60.9 | 69.9 | 64. | 61.8 | 67.9 | 63.3 | 60.5 |
| 12 Min. | 66.5 | 65.1 | 62.2 | 65.9 | 64.9 | 62.1 | 66.9 | 63.8 | 60.3 | 66.9 | 63.8 | 61.8 | 67. | 62.8 | 60.3 |
| 13 Max. | 72.5 | 67.9 | 63. | 71.8 | 66.5 | 62.3 | 66.8 | 64.6 | 61. | 69.9 | 64.4 | 62.5 | 67.8 | 63.9 | 61.1 |
| 13 Min. | 63.8 | 63.9 | 62.1 | 62.1 | 62.8 | 61.7 | 65. | 63.9 | 60.9 | 65. | 63.9 | 62.1 | 66. | 63.9 | 61. |
| 14 Max. | 65.6 | 65.7 | 63.8 | 64.2 | 64.3 | 63. | 66.6 | 65. | 61.7 | 66. | 65. | 62.9 | 66. | 64.3 | 62. |
| 14 Min. | 63.9 | 63.4 | 62.1 | 63. | 62.5 | 61.4 | 64.7 | 63.8 | 61.3 | 64.6 | 63.7 | 62.5 | 65.9 | 64. | 61.8 |
| 15 Max. | 70.3 | 66.2 | 61.8 | 71. | 66. | 61.3 | 67.3 | 62.7 | 60.7 | 68.6 | 62.8 | 61.5 | 66.5 | 63.3 | 61.7 |
| 15 Min. | 62.8 | 62.2 | 61.2 | 62.1 | 61.8 | 60.7 | 63.6 | 62.4 | 60.5 | 63.2 | 62.3 | 61.2 | 64.8 | 63.2 | 61.5 |
| 17 Max. | 72. | 67.6 | 63.5 | 72.5 | 67.2 | 63.1 | 66. | 64.8 | 61.5 | 69.4 | 64.5 | 63. | 66.2 | 64.7 | 62. |
| 17 Min. | 63. | 63.6 | 62.3 | 62.6 | 63. | 62. | 64.8 | 63.9 | 61.3 | 65. | 63.9 | 62.2 | 66.9 | 64.5 | 62. |
| 18 Max. | 66. | 65.4 | 63.2 | 66. | 64.8 | 62.7 | 66.2 | 64.5 | 61.3 | 66.9 | 64.6 | 63. | 67.7 | 64.9 | 62.3 |
| 18 Min. | 63. | 63. | 62.3 | 61.5 | 62. | 61.7 | 63.8 | 63.4 | 61.2 | 63.7 | 63.3 | 62.2 | 65.6 | 64.4 | 61.8 |
| 19 Max. | 70.5 | 66.9 | 62.7 | 70.4 | 66. | 62.1 | 67.7 | 63.7 | 61.1 | 68.7 | 63.7 | 62.2 | 66.9 | 64.1 | 62.2 |
| 19 Min. | 63.5 | 63.9 | 62.2 | 62.5 | 63. | 61.6 | 64.7 | 63.3 | 61. | 61. | 63.2 | 62. | 65.6 | 64. | 62. |
| 20 Max. | 70.8 | 66.6 | 62.9 | 70.8 | 65.8 | 62.2 | 67.4 | 63.7 | 61.4 | 68.6 | 63.6 | 62.3 | 66.6 | 64.2 | 62.1 |
| 20 Min. | 63.1 | 63.4 | 62.3 | 62. | 62.5 | 61.7 | 64.2 | 63.3 | 61. | 64.1 | 63.3 | 62. | 65.6 | 63.9 | 61.9 |
| 21 Max. | 72. | 67.5 | 63.2 | 71.6 | 66.3 | 62.7 | 66.3 | 64.3 | 62.5 | 69. | 64.2 | 62.8 | 67.4 | 64.5 | 62.5 |
| 21 Min. | 63.9 | 64.1 | 63. | 63. | 63.2 | 62.3 | 65. | 63.9 | 61.3 | 65. | 63.9 | 62.4 | 66.4 | 64.2 | 62.0 |
| 22 Max. | 74.3 | 69. | 63.6 | 73.5 | 67.4 | 63.1 | 69.8 | 64.8 | 62. | 71. | 64.7 | 63. | 66.2 | 64.8 | 62.5 |
| 22 Min. | 63.6 | 64.4 | 63. | 62.8 | 63.5 | 62.6 | 65.4 | 64.4 | 61.8 | 64.7 | 64.1 | 62.9 | 66.4 | 64.6 | 62.2 |
| 24 Max. | 74. | 70. | 69. | 73. | 68.5 | 65.2 | 71.2 | 67.1 | 63.3 | 71.0 | 66.7 | 64.5 | 70.6 | 69.3 | 63.2 |
| 24 Min. | 68.4 | 67.6 | 65.3 | 67.3 | 66.0 | 64.5 | 68.8 | 66.5 | 63.0 | 68.0 | 66.2 | 64.3 | 69.6 | 66.0 | 62.9 |
| 25 Max. | 77.0 | 71.4 | 66.1 | 75.6 | 69.6 | 65.1 | 72.7 | 67.3 | 64.0 | 74.5 | 66.8 | 65.0 | 71.2 | 67.1 | 64.0 |
| 25 Min. | 67.8 | 67.5 | 65.3 | 66.5 | 66.0 | 64.4 | 68.7 | 66.5 | 63.5 | 68.4 | 66.5 | 64.5 | 69.6 | 66.4 | 63.5 |
| 26 Max. | 77.0 | 72.5 | 66.9 | 75.0 | 70.7 | 66.0 | 73.9 | 68.4 | 64.0 | 74.5 | 68.1 | 65.8 | 73.0 | 66.0 | 64.7 |
| 26 Min. | 69.6 | 69.2 | 66.4 | 68.0 | 67.7 | 65.3 | 70.3 | 67.8 | 63.6 | 69.5 | 67.3 | 65.1 | 71.0 | 67.1 | 63.7 |
| 27 Max. | 75.2 | 71.2 | 67.5 | 73.4 | 69.4 | 66.3 | 72.5 | 69.0 | 65.0 | 73.0 | 66.7 | 66.2 | 72.5 | 68.6 | 65.1 |
| 27 Min. | 69.4 | 68.9 | 66.4 | 68.3 | 67.5 | 65.3 | 70.0 | 68.0 | 64.7 | 69.7 | 67.5 | 65.5 | 71.3 | 68.1 | 65.0 |
| 28 Max. | 77.5 | 72.3 | 67.1 | 75.4 | 70.3 | 66.0 | 73.9 | 68.6 | 65.0 | 74.8 | 68.3 | 69.0 | 73.0 | 68.8 | 65.7 |
| 28 Min. | 68.8 | 68.3 | 66.2 | 67.7 | 66.9 | 65.3 | 70.0 | 68.0 | 64.8 | 69.4 | 67.3 | 65.8 | 71.0 | 68.3 | 65.2 |
| 29 Max. | 74.8 | 70.2 | 67.9 | 73.3 | 69.1 | 66.8 | 71.9 | 69.5 | 65.3 | 72.3 | 69.0 | 66.7 | 73.5 | 66.3 | 65.9 |
| 29 Min. | 70.2 | 69.6 | 64.8 | 69.2 | 68.2 | 63.9 | 71.1 | 66.1 | 62.9 | 70.9 | 66.0 | 63.8 | 71.5 | 66.3 | 63.2 |
| Monthly range | 7.06 | 3.32 | 0.92 | 6.43 | 3.32 | 0.95 | 3.09 | 0.67 | 0.47 | 4.56 | 0.60 | 0.56 | 1.62 | 0.48 | 0.44 |

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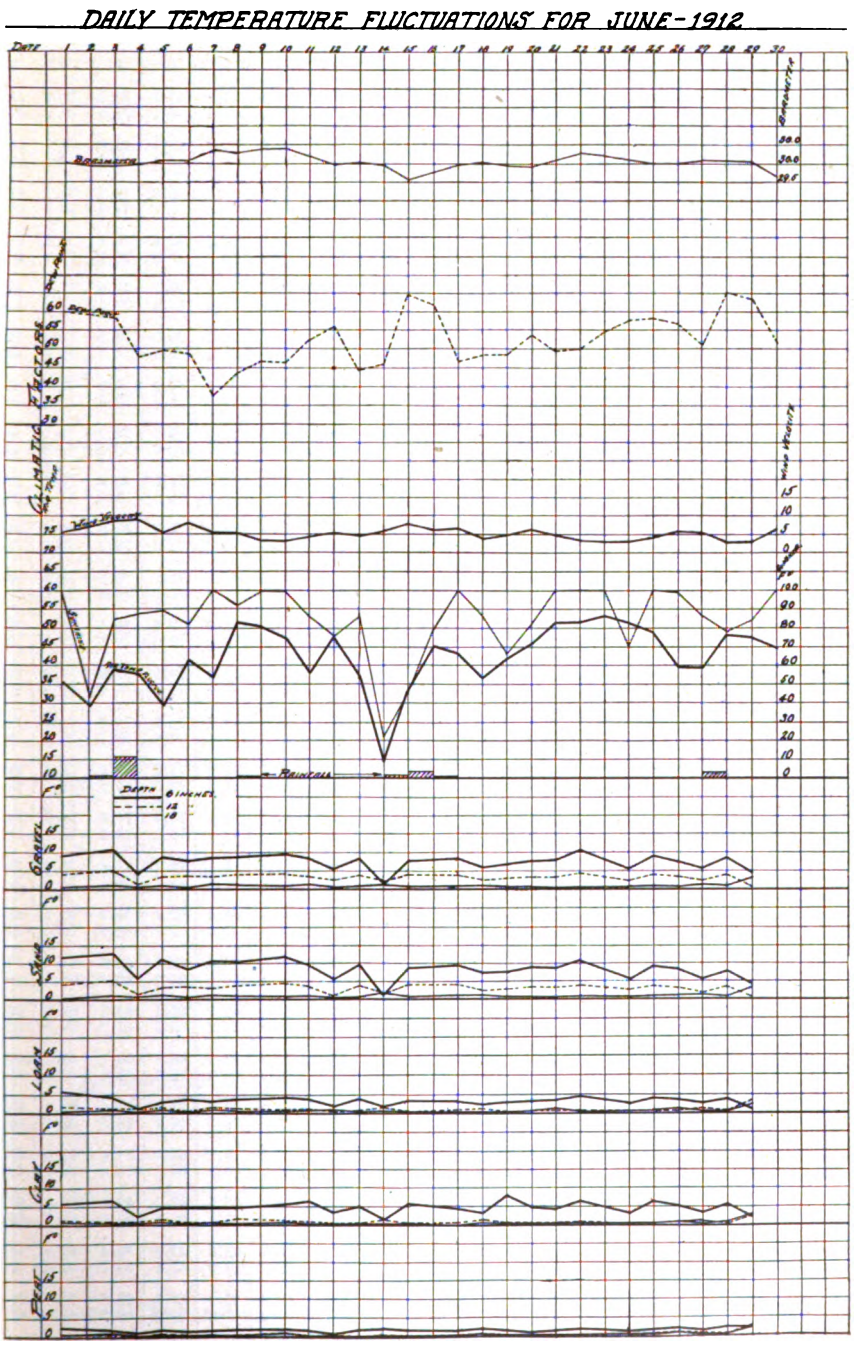


FIG. 22.

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TABLE 37.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, JULY, 1912.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 76.3 | 71.4 | 68.7 | 74.0 | 69.3 | 67.4 | 72.6 | 70.3 | 69.3 | 73.2 | 68.8 | 67.8 | 73.3 | 70.4 | 67.9 |
| 1 Min. | 68.0 | 68.1 | 66.5 | 67.0 | 66.3 | 65.5 | 69.1 | 68.2 | 65.3 | 69.2 | 67.7 | 66.1 | 71.8 | 69.1 | 66.0 |
| 2 Max. | 76.5 | 71.8 | 68.8 | 74.3 | 69.7 | 67.5 | 73.3 | 70.2 | 66.5 | 73.8 | 70.0 | 67.6 | 74.0 | 70.3 | 67.2 |
| 2 Min. | 70.7 | 68.7 | 66.4 | 69.0 | 67.1 | 65.3 | 70.1 | 68.0 | 64.7 | 69.7 | 67.5 | 65.3 | 71.2 | 6.90 | 66.0 |
| 3 Max. | 79.8 | 75.0 | 69.2 | 77.2 | 72.4 | 68.0 | 76.5 | 70.8 | 66.9 | 77.1 | 70.3 | 68.2 | 76.1 | 71.1 | 67.5 |
| 3 Min. | 72.0 | 71.3 | 68.8 | 71.0 | 70.0 | 67.8 | 73.0 | 70.5 | 66.5 | 72.4 | 70.0 | 67.6 | 74.3 | 70.2 | 66.8 |
| 4 Max. | 80.4 | 75.0 | 69.4 | 77.6 | 72.4 | 66.0 | 76.6 | 71.0 | 66.6 | 77.6 | 70.3 | 67.9 | 76.1 | 70.8 | 67.2 |
| 4 Min. | 71.9 | 70.6 | 68.0 | 70.8 | 69.0 | 67.0 | 72.1 | 69.9 | 66.0 | 71.9 | 69.3 | 67.3 | 73.4 | 70.0 | 66.3 |
| 5 Max. | 80.0 | 75.8 | 71.0 | 77.8 | 73.2 | 69.4 | 77.4 | 72.4 | 67.6 | 77.9 | 71.3 | 68.7 | 77.0 | 71.5 | 67.5 |
| 5 Min. | 74.8 | 72.7 | 69.6 | 73.0 | 71.1 | 68.2 | 74.7 | 71.3 | 67.0 | 74.1 | 71.0 | 68.4 | 75.6 | 71.2 | 67.0 |
| 6 Max. | 80.8 | 77.1 | 71.5 | 78.6 | 74.6 | 70.2 | 78.9 | 73.4 | 69.1 | 79.2 | 72.9 | 70.2 | 78.5 | 73.4 | 68.8 |
| 6 Min. | 74.9 | 73.8 | 71.0 | 74.0 | 72.1 | 69.5 | 75.7 | 72.7 | 68.5 | 74.8 | 71.9 | 69.3 | 76.2 | 72.0 | 67.8 |
| 8 Max. | 80.8 | 75.7 | 70.6 | 80.3 | 74.3 | 69.6 | 77.4 | 72.3 | 69.0 | 78.4 | 71.9 | 70.0 | 77.3 | 73.2 | 69.6 |
| 8 Min. | 72.3 | 71.9 | 70.0 | 71.3 | 70.8 | 69.1 | 73.7 | 72.0 | 68.7 | 73.0 | 71.3 | 69.6 | 75.5 | 72.9 | 69.6 |
| 9 Max. | 83.1 | 77.2 | 71.4 | 81.5 | 75.5 | 70.4 | 78.5 | 73.0 | 69.0 | 79.7 | 72.3 | 70.3 | 78.1 | 73.5 | 69.9 |
| 9 Min. | 74.2 | 73.0 | 70.4 | 73.0 | 71.7 | 69.5 | 75.0 | 72.2 | 68.3 | 74.3 | 71.7 | 69.7 | 76.2 | 72.9 | 69.3 |
| 10 Max. | 82.5 | 78.8 | 73.2 | 80.4 | 76.8 | 72.3 | 80.3 | 75.6 | 71.0 | 80.7 | 74.6 | 72.0 | 80.4 | 75.0 | 71.3 |
| 10 Min. | 76.4 | 75.1 | 72.2 | 75.3 | 73.8 | 71.3 | 77.0 | 74.0 | 69.5 | 76.3 | 73.4 | 71.0 | 78.1 | 74.0 | 70.0 |
| 11 Max. | 83.7 | 78.8 | 73.7 | 81.2 | 76.5 | 72.5 | 80.4 | 75.4 | 71.1 | 81.0 | 75.8 | 72.7 | 80.0 | 75.7 | 71.0 |
| 11 Min. | 76.2 | 75.5 | 73.1 | 75.1 | 74.0 | 72.0 | 77.2 | 74.8 | 71.0 | 75.3 | 74.0 | 72.0 | 78.2 | 75.2 | 71.4 |
| 12 Max. | 81.5 | 77.7 | 74.0 | 79.3 | 75.4 | 72.8 | 79.4 | 75.8 | 71.3 | 79.6 | 75.0 | 72.3 | 79.3 | 75.9 | 72.0 |
| 12 Min. | 75.6 | 75.0 | 73.0 | 74.4 | 73.3 | 71.9 | 76.6 | 75.0 | 71.2 | 75.7 | 74.0 | 72.1 | 78.0 | 75.6 | 71.8 |
| 13 Max. | 76.3 | 76.1 | 74.0 | 75.3 | 74.9 | 72.7 | 77.9 | 75.9 | 71.8 | 76.7 | 75.6 | 72.0 | 79.4 | 75.9 | 72.3 |
| 13 Min. | 74.0 | 73.8 | 72.2 | 72.4 | 72.8 | 71.2 | 75.3 | 74.3 | 71.3 | 74.6 | 73.2 | 72.0 | 76.7 | 75.3 | 72.2 |
| 15 Max. | 80.0 | 78.9 | 72.3 | 80.2 | 76.4 | 72.0 | 78.0 | 73.9 | 70.3 | 70.4 | 73.8 | 71.5 | 78.0 | 74.4 | 71.8 |
| 15 Min. | 74.5 | 74.2 | 71.9 | 74.1 | 74.0 | 71.0 | 75.1 | 73.0 | 70.0 | 75.9 | 72.9 | 71.0 | 76.2 | 73.9 | 71.2 |
| 16 Max. | 78.4 | 73.9 | 72.0 | 79.0 | 73.3 | 71.3 | 75.0 | 73.0 | 70.8 | 70.1 | 73.2 | 71.9 | 75.7 | 74.2 | 71.7 |
| 16 Min. | 69.0 | 70.0 | 70.2 | 66.3 | 68.8 | 69.7 | 71.4 | 71.9 | 70.0 | 71.0 | 71.6 | 70.8 | 73.7 | 73.4 | 71.3 |
| 17 Max. | 81.8 | 76.6 | 71.9 | 82.3 | 76.1 | 71.3 | 77.8 | 73.2 | 70.3 | 78.9 | 72.9 | 71.2 | 76.9 | 73.6 | 71.4 |
| 17 Min. | 73.0 | 72.5 | 71.0 | 71.5 | 71.6 | 70.2 | 73.8 | 71.9 | 69.4 | 73.1 | 71.3 | 70.0 | 74.2 | 72.7 | 70.4 |
| 18 Max. | 74.0 | 74.5 | 73.0 | 72.0 | 73.1 | 72.2 | 75.7 | 74.0 | 70.7 | 74.3 | 73.5 | 71.7 | 77.3 | 74.0 | 71.2 |
| 18 Min. | 71.3 | 71.3 | 71.3 | 70.1 | 70.2 | 70.3 | 72.6 | 72.9 | 70.2 | 71.5 | 72.0 | 71.2 | 74.3 | 73.8 | 71.0 |
| 19 Max. | 71.1 | 68.1 | 69.2 | 72.0 | 68.2 | 68.4 | 69.4 | 71.1 | 70.0 | 70.2 | 70.1 | 70.2 | 71.4 | 72.0 | 71.2 |
| 19 Min. | 63.6 | 64.8 | 66.8 | 61.6 | 63.8 | 66.1 | 66.0 | 68.6 | 68.2 | 65.1 | 67.8 | 68.1 | 69.1 | 71.3 | 70.3 |
| 20 Max. | 65.6 | 66.4 | 67.2 | 64.9 | 66.0 | 67.6 | 67.6 | 68.8 | 67.4 | 66.9 | 68.0 | 67.7 | 70.3 | 70.5 | 69.0 |
| 20 Min. | 65.2 | 65.6 | 66.2 | 64.2 | 65.2 | 66.0 | 66.7 | 67.5 | 67.0 | 66.3 | 67.0 | 67.1 | 68.9 | 70.0 | 69.3 |
| 22 Max. | 71.0 | 67.3 | 65.1 | 73.8 | 68.1 | 65.0 | 67.9 | 65.8 | 65.3 | 69.6 | 65.4 | 65.5 | 68.9 | 67.7 | 67.7 |
| 22 Min. | 63.3 | 64.0 | 64.2 | 62.5 | 63.6 | 64.0 | 64.6 | 65.0 | 64.6 | 64.3 | 64.6 | 64.8 | 65.4 | 66.4 | 66.5 |
| 23 Max. | 69.3 | 67.6 | 66. | 70.1 | 68.0 | 66.2 | 68.0 | 66.2 | 65.0 | 69.2 | 66.5 | 65.0 | 68.0 | 66.8 | 66.2 |
| 23 Min. | 65.5 | 66.0 | 65.8 | 65.6 | 66.3 | 66.0 | 66.5 | 66.0 | 64.7 | 67.0 | 66.2 | 65.5 | 67.3 | 66.6 | 66.1 |
| 24 Max. | 73.0 | 69.8 | 68.2 | 73.4 | 69.9 | 68.2 | 70.1 | 66.9 | 65.4 | 71.5 | 67.0 | 66.1 | 68.7 | 66.9 | 69.1 |
| 24 Min. | 67.5 | 67.0 | 66.0 | 67.3 | 66.9 | 66.0 | 67.7 | 66.2 | 64.7 | 67.9 | 66.6 | 65.5 | 67.9 | 66.2 | 65.3 |
| 25 Max. | 76.1 | 72.2 | 68.0 | 78.0 | 73.0 | 68.1 | 72.9 | 68.7 | 68.0 | 75.0 | 69.0 | 67.2 | 71.6 | 66.0 | 66.3 |
| 25 Min. | 70.1 | 69.4 | 67.6 | 69.4 | 69.3 | 67.6 | 70.2 | 68.2 | 65.8 | 70.7 | 68.3 | 66.9 | 70.3 | 67.6 | 66.1 |
| 26 Max. | 73.0 | 70.1 | 69.0 | 73.6 | 70.1 | 69.0 | 70.8 | 68.9 | 68.9 | 72.2 | 70.1 | 68.3 | 71.4 | 69.0 | 67.3 |
| 26 Min. | 68.3 | 68.2 | 68.0 | 67.9 | 68.0 | 67.8 | 69.0 | 68.9 | 66.8 | 69.3 | 69.1 | 68.0 | 70.0 | 69.1 | 66.8 |
| 27 Max. | 74.8 | 70.1 | 67.2 | 75.6 | 70.0 | 67.0 | 71.0 | 68.2 | 66.1 | 72.7 | 68.5 | 67.7 | 69.3 | 68.2 | 66.8 |
| 27 Min. | 65.5 | 66.3 | 66.1 | 64.2 | 65.9 | 66.0 | 67.3 | 67.1 | 65.5 | 67.4 | 67.1 | 66.2 | 68.0 | 67.7 | 66.3 |
| 29 Max. | 71.0 | 69.0 | 67.6 | 71.9 | 68.9 | 67.6 | 69.9 | 69.2 | 67.2 | 70.6 | 69.0 | 67.9 | 70.4 | 69.4 | 68.0 |
| 29 Min. | 66.8 | 67.2 | 67.1 | 65.4 | 66.2 | 66.7 | 68.4 | 68.2 | 66.9 | 67.9 | 68.0 | 67.4 | 69.7 | 69.0 | 67.6 |
| 30 Max. | 69.8 | 68.1 | 67.0 | 70.1 | 68.2 | 67.0 | 69.0 | 68.3 | 66.9 | 69.9 | 68.1 | 67.5 | 69.6 | 69.1 | 68.0 |
| 30 Min. | 64.8 | 65.4 | 66.1 | 63.8 | 65.0 | 65.9 | 66.1 | 67.2 | 66.4 | 66.2 | 67.2 | 67.0 | 68.2 | 68.9 | 67.7 |
| 31 Max. | 68.9 | 66.6 | 66.2 | 70.3 | 66.9 | 69.0 | 67.1 | 66.9 | 66.6 | 68.3 | 66.9 | 66.5 | 68.0 | 68.2 | 67.5 |
| 31 Min. | 63.3 | 64.5 | 65.2 | 61.9 | 63.8 | 65.2 | 65.1 | 66.0 | 65.7 | 65.0 | 66.0 | 65.9 | 67.0 | 67.7 | 67.3 |
| Monthly range | 6.17 | 3.00 | 1.94 | 6.78 | 3.00 | 1.03 | 2.94 | 1.07 | 0.63 | 4.07 | 1.12 | 0.78 | 1.77 | 0.67 | 0.50 |

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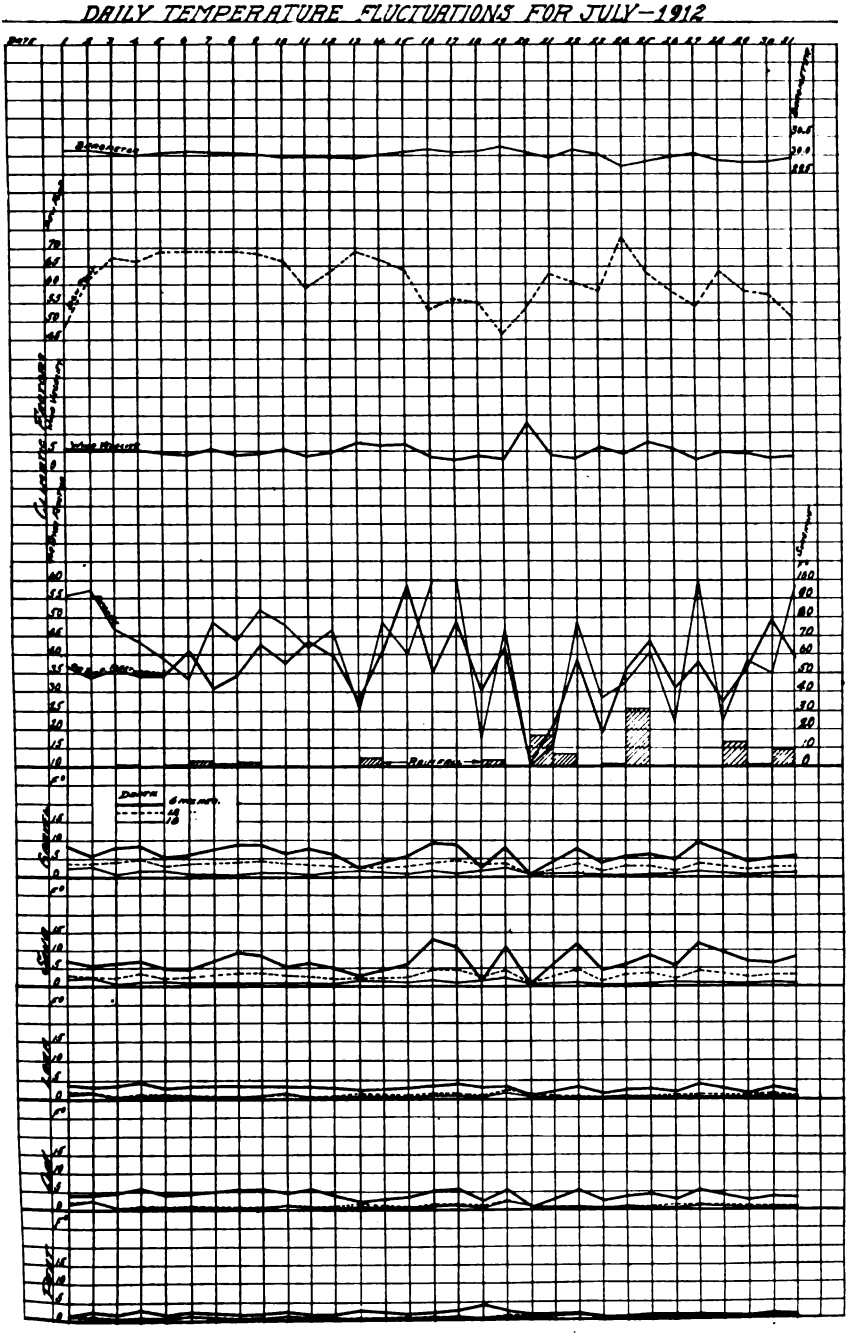


FIG. 23.

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TABLE 38.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL AUGUST, 1912.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 69.6 | 68.1 | 65.5 | 69.9 | 66.5 | 65.6 | 66.1 | 66.2 | 65.4 | 68.0 | 66.2 | 66.0 | 67.1 | 67.5 | 66.9 |
| 1 Min. | 62.4 | 63.3 | 64.4 | 61.9 | 63.3 | 64.5 | 63.8 | 65.0 | 64.6 | 64.3 | 65.0 | 65.0 | 65.9 | 66.3 | 66.1 |
| 2 Max. | 69.7 | 65.6 | 65.2 | 66.1 | 65.2 | 65.3 | 65.9 | 65.7 | 64.3 | 66.4 | 65.9 | 65.4 | 66.1 | 66.1 | 66.9 |
| 2 Min. | 64.0 | 64.4 | 64.8 | 63.4 | 64.0 | 64.6 | 64.8 | 65.0 | 64.7 | 65.0 | 65.2 | 65.1 | 65.8 | 66.0 | 66.0 |
| 3 Max. | 63.4 | 62.4 | 64.6 | 64.2 | 62.6 | 63.7 | 62.9 | 64.6 | 64.3 | 63.3 | 64.4 | 66.1 | 64.5 | 65.6 | 65.5 |
| 3 Min. | 59.4 | 61.0 | 62.8 | 58.0 | 60.5 | 62.6 | 61.2 | 63.2 | 63.6 | 61.0 | 63.0 | 64.0 | 63.2 | 65.0 | 65.3 |
| 5 Max. | 71.4 | 67.8 | 64.1 | 72.6 | 67.8 | 64.2 | 67.7 | 64.0 | 63.1 | 69 3 | 64.3 | 63.7 | 65.9 | 64.2 | 64.3 |
| 5 Min. | 62.8 | 63.3 | 63.3 | 62.0 | 63.2 | 63.3 | 63.4 | 63.4 | 62.7 | 63.8 | 63.5 | 63.2 | 64.0 | 63.9 | 63.9 |
| 6 Max. | 72.1 | 68.6 | 65.1 | 72.9 | 68.9 | 65.1 | 66.6 | 65.2 | 63.6 | 70.2 | 65.7 | 64.5 | 67.1 | 64.9 | 64.1 |
| 6 Min. | 65.2 | 65.4 | 65.0 | 64.2 | 65.0 | 64.8 | 65.7 | 65.1 | 63.3 | 65.9 | 65.2 | 64.2 | 66.0 | 64.5 | 64.0 |
| 7 Max. | 72.3 | 69.7 | 66.1 | 73.0 | 69.5 | 66.1 | 70.1 | 66.5 | 64.8 | 71.2 | 69.7 | 65.4 | 66.8 | 65.9 | 64.9 |
| 7 Min. | 67.4 | 67.0 | 65.9 | 66.9 | 66.6 | 65.7 | 67.5 | 66.2 | 64.4 | 67.9 | 66.2 | 65.3 | 67.3 | 65.4 | 64.4 |
| 8 Max. | 73.3 | 69.9 | 69.5 | 74.1 | 69.9 | 66.2 | 70.5 | 67.1 | 65.0 | 71.7 | 67.2 | 66.9 | 69.3 | 66.4 | 65.6 |
| 8 Min. | 67.5 | 67.2 | 66.1 | 66.8 | 66.7 | 65.9 | 68.0 | 66.9 | 65.0 | 68.2 | 66.9 | 65.9 | 68.3 | 66.2 | 64.9 |
| 9 Max. | 71. | 66.4 | 66.9 | 71.1 | 69.6 | 66.9 | 70.2 | 67.6 | 65.6 | 70.8 | 68.6 | 66.3 | 70.0 | 67.9 | 65.3 |
| 9 Min. | 68.6 | 67.5 | 66.0 | 67.9 | 67.8 | 66.7 | 68.5 | 66.9 | 64.8 | 68.9 | 67.1 | 65.9 | 69.2 | 66.5 | 64.8 |
| 10 Max. | 66.9 | 67.9 | 69.7 | 71.6 | 67.9 | 65.1 | 68.9 | 67.8 | 65.8 | 69.4 | 67.5 | 66.5 | 69.4 | 67.5 | 65.6 |
| 10 Min. | 66.2 | 66.1 | 65.9 | 65.3 | 65.8 | 65.4 | 67.1 | 66.9 | 65.2 | 67.0 | 66.6 | 65.9 | 68.4 | 67.0 | 65.6 |
| 12 Max. | 70.9 | 68.0 | 65.9 | 72.9 | 66.4 | 65.7 | 66.8 | 66.6 | 65.2 | 70.0 | 66.3 | 65.9 | 68.2 | 67.3 | 66.1 |
| 12 Min. | 65.3 | 65.3 | 64.5 | 64.5 | 64.7 | 64.3 | 65.9 | 65.3 | 64.3 | 66.1 | 65.1 | 64.9 | 66.6 | 66.2 | 65.5 |
| 13 Max. | 75.6 | 71.6 | 68.9 | 77.0 | 71.4 | 66.6 | 71.4 | 67.1 | 65.0 | 73.2 | 67.4 | 66.9 | 70.9 | 67.1 | 65.8 |
| 13 Min. | 68.3 | 67.8 | 66.0 | 68.6 | 67.9 | 66.0 | 68.3 | 66.5 | 64.6 | 69.3 | 66.7 | 65.5 | 69.3 | 66.6 | 65.2 |
| 14 Max. | 76.9 | 72.6 | 68.6 | 77.9 | 72.7 | 68.3 | 73.1 | 69.6 | 66.0 | 74.9 | 69.2 | 67.2 | 72.2 | 68.3 | 66.6 |
| 14 Min. | 69.9 | 69.3 | 67.8 | 69.3 | 68.9 | 67.3 | 70.0 | 68.3 | 65.7 | 70.8 | 68.7 | 67.1 | 71.0 | 68.0 | 65.8 |
| 15 Max. | 73.2 | 70.3 | 69.4 | 73.9 | 70.6 | 69.0 | 71.6 | 70.0 | 67.0 | 71.6 | 70.0 | 68.3 | 72.1 | 69.3 | 66.7 |
| 15 Min. | 68.3 | 68.2 | 67.8 | 67.0 | 67.3 | 67.2 | 69.0 | 68.8 | 66.5 | 68.9 | 68.6 | 67.5 | 70.5 | 69.0 | 66.6 |
| 16 Max. | 73.4 | 66.9 | 68.2 | 73.9 | 69.6 | 67.7 | 70.6 | 69.3 | 67.0 | 71.3 | 69.0 | 68.6 | 70.4 | 69.3 | 66.3 |
| 16 Min. | 66.0 | 66.5 | 66.5 | 64.5 | 65.5 | 61.2 | 67.3 | 67.7 | 66.1 | 66.9 | 67.4 | 66.5 | 68.8 | 68.4 | 67.0 |
| 17 Max. | 69.4 | 67.7 | 67.8 | 69.6 | 67.0 | 67.1 | 68.4 | 68.4 | 66.1 | 66.3 | 66.6 | 67.1 | 66.8 | 68.4 | 67.1 |
| 17 Min. | 66.0 | 66.3 | 66.2 | 65.2 | 65.6 | 66.0 | 67.1 | 67.2 | 66.1 | 66.4 | 66.7 | 66.4 | 68.5 | 68.1 | 66.9 |
| 19 Max. | 70.7 | 70.0 | 68.2 | 70.2 | 69.4 | 66.0 | 71.6 | 66.9 | 66.1 | 70.1 | 68.6 | 67.6 | 71.2 | 68.2 | 66.7 |
| 19 Min. | 69.4 | 69.0 | 67.3 | 69.0 | 68.3 | 67.0 | 69.9 | 68.2 | 66.0 | 69.4 | 68.0 | 66.8 | 70.2 | 68.2 | 66.5 |
| 20 Max. | 72.6 | 70.0 | 67.5 | 74.0 | 69.6 | 67.2 | 70.7 | 69.4 | 66.4 | 71.3 | 68.6 | 67.1 | 70.2 | 69.3 | 66.6 |
| 20 Min. | 68.0 | 67.4 | 66.7 | 67.4 | 66.9 | 66.3 | 68.2 | 67.5 | 65.9 | 68.0 | 67.5 | 66.7 | 69.3 | 68.3 | 66.6 |
| 21 Max. | 74.3 | 71.0 | 68.6 | 75.9 | 71.5 | 66.6 | 71.8 | 69.6 | 67.0 | 73.1 | 66.9 | 67.5 | 71.2 | 69.2 | 67.8 |
| 21 Min. | 67.5 | 67.5 | 67.2 | 67.2 | 67.2 | 66.9 | 68.3 | 68.0 | 66.0 | 68.3 | 67.8 | 67.0 | 69.6 | 68.5 | 66.9 |
| 22 Max. | 71.2 | 70.6 | 66.0 | 71.3 | 70.0 | 69.0 | 70.7 | 69.6 | 67.4 | 71.1 | 69.7 | 66.3 | 71.0 | 69.5 | 66.6 |
| 22 Min. | 68.3 | 68.4 | 68.2 | 67.6 | 68.2 | 68.0 | 69.2 | 69.0 | 67.3 | 69.6 | 69.0 | 68.1 | 70.2 | 69.4 | 67.9 |
| 23 Max. | 69.7 | 67.1 | 67.7 | 68.1 | 67.0 | 67.4 | 67.7 | 66.8 | 67.3 | 68.2 | 66.4 | 66.0 | 69.1 | 66.3 | 68.1 |
| 23 Min. | 65.0 | 65.6 | 66.2 | 64.0 | 65.2 | 66.2 | 66.2 | 67.3 | 66.5 | 66.0 | 67.1 | 67.1 | 67.8 | 66.8 | 66.9 |
| 24 Max. | 71.7 | 67.5 | 66.0 | 72.7 | 67.6 | 65.9 | 67.8 | 66.9 | 66.1 | 66.3 | 66.4 | 66.4 | 66.6 | 66.6 | 67.6 |
| 24 Min. | 62.8 | 63.8 | 64.8 | 61.7 | 63.4 | 64.5 | 64.2 | 65.4 | 65.2 | 64.3 | 65.4 | 65.3 | 65.3 | 66.8 | 66.8 |
| 26 Max. | 76.2 | 75.3 | 70.4 | 76.3 | 75.6 | 70.1 | 76.1 | 71.6 | 67.5 | 77.2 | 71.6 | 66.9 | 74.8 | 66.4 | 66.9 |
| 26 Min. | 72.5 | 71.7 | 69.0 | 71.8 | 71.3 | 68.9 | 72.4 | 69.0 | 65.6 | 72.3 | 69.3 | 66.9 | 72.4 | 67.2 | 65.4 |
| 27 Max. | 75.6 | 72.1 | 70.3 | 75.6 | 71.6 | 66.9 | 72.7 | 71.2 | 66.7 | 73.2 | 71.0 | 66.4 | 73.6 | 70.6 | 66.3 |
| 27 Min. | 69.0 | 69.5 | 69.4 | 67.9 | 68.7 | 69.0 | 70.1 | 70.3 | 68.0 | 69.7 | 69.9 | 69.2 | 71.6 | 70.0 | 67.4 |
| 28 Max. | 66.1 | 66.3 | 66.6 | 67.6 | 66.7 | 66.0 | 70.1 | 70.7 | 66.5 | 66.6 | 70.6 | 66.2 | 71.7 | 70.7 | 66.7 |
| 28 Min. | 65.5 | 66.0 | 66.9 | 64.6 | 65.4 | 66.4 | 67.0 | 68.0 | 67.2 | 66.3 | 67.3 | 67.3 | 69.1 | 68.0 | 68.0 |
| 30 Max. | 62.0 | 62.6 | 64.6 | 61.8 | 62.0 | 64.4 | 63.5 | 65.2 | 65.0 | 66.2 | 64.9 | 65.0 | 66.9 | 66.6 | 66.9 |
| 30 Min. | 60.3 | 61.0 | 62.2 | 59.1 | 60.5 | 62.0 | 61.7 | 63.0 | 63.1 | 62.0 | 62.3 | 63.5 | 65.6 | 63.8 | 65.8 |
| 29 Max. | 67.6 | 65.6 | 65.8 | 67.3 | 65.3 | 65.2 | 66. | 66.8 | 66.3 | 66.6 | 66.1 | 66.2 | 66.4 | 67.0 | 67.6 |
| 29 Min. | 63.1 | 63.8 | 65.0 | 62.2 | 63.4 | 64.6 | 64.6 | 65.6 | 65.6 | 64.0 | 65.4 | 65.8 | 67.9 | 66.0 | 67.7 |
| 31 Max. | 71.7 | 67.6 | 63.2 | 73.6 | 67.4 | 63.6 | 67.2 | 63.3 | 62.8 | 69.3 | 63.5 | 63.9 | 65.7 | 64.6 | 65.1 |
| 31 Min. | 60.6 | 61.1 | 62.0 | 60.0 | 61.0 | 61.8 | 61.7 | 62.8 | 62.8 | 61.4 | 62.4 | 62.7 | 63.4 | 63.2 | 64.7 |
| Monthly range. | 5.22 | 2.63 | 1.66 | 0.59 | 2.95 | 1.26 | 2.56 | 3.31 | 0.60 | 3.42 | 1.12 | 0.76 | 1.34 | 0.75 | 0.51 |

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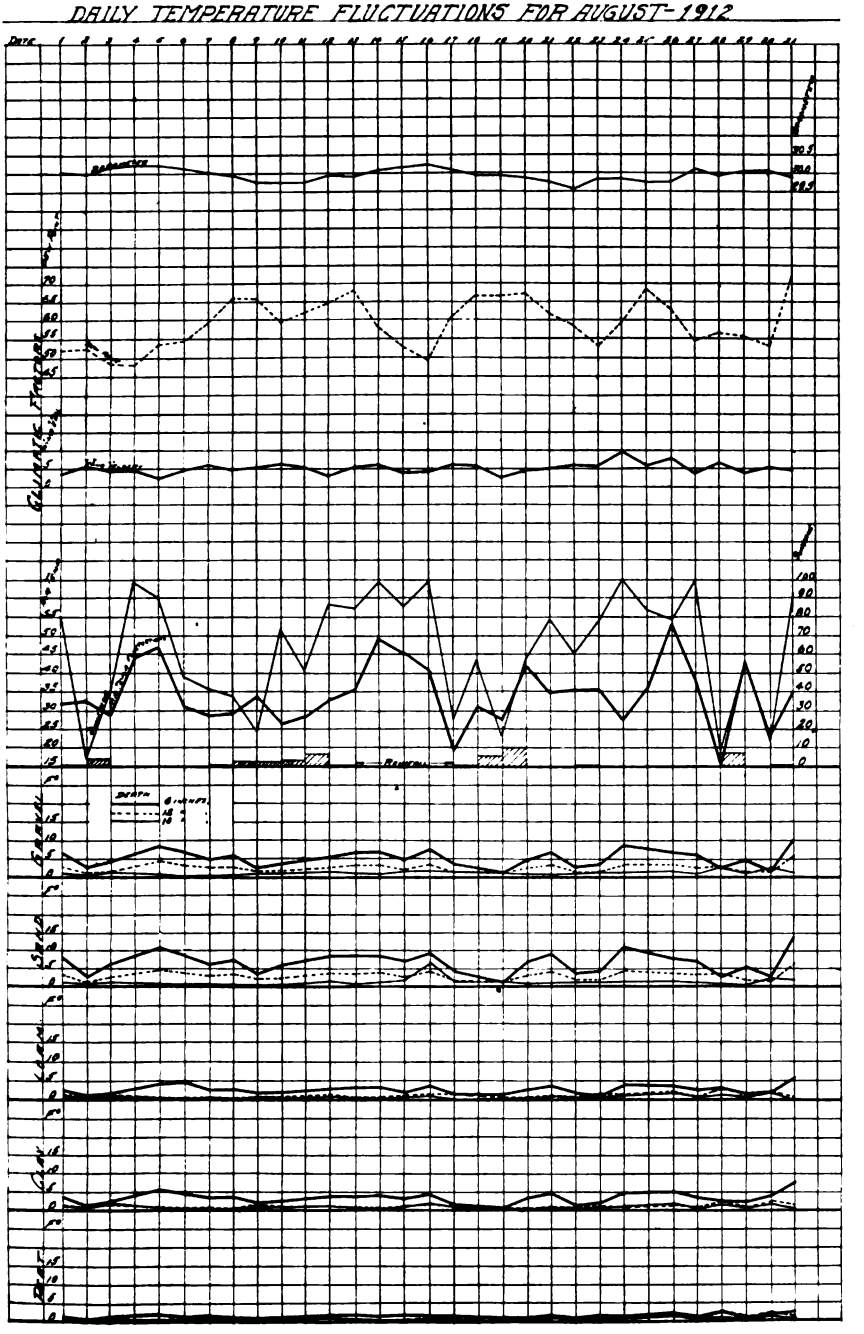


FIG. 24.

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TABLE 39.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, SEPTEMBER, 1912.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12 | 18″ |
| 2 Max... | 38.5 | 73.9 | 68.9 | 79.2 | 73.9 | 68.6 | 74.0 | 69.1 | 68.9 | 75.9 | 66.4 | 67.2 | 72.0 | 67.8 | 65.6 |
| 2 Min.... | 31.3 | 70.2 | 68.0 | 71.0 | 70.0 | 68.0 | 71.2 | 68.5 | 65.6 | 71.2 | 68.7 | 67.1 | 71.2 | 67.4 | 65.3 |
| 3 Max... | 77.0 | 73.2 | 70.0 | 78.2 | 73.3 | 69.3 | 74.4 | 70.4 | 67.6 | 75.0 | 71.0 | 68.8 | 73.9 | 69.3 | 66.6 |
| 3 Min.... | 71.6 | 70.9 | 69.3 | 70.8 | 70.2 | 69.0 | 72.0 | 70.0 | 67.0 | 71.9 | 69.9 | 68.1 | 72.6 | 69.0 | 66.2 |
| 4 Max... | 76.1 | 73.6 | 70.5 | 77.0 | 72.8 | 70.0 | 74.0 | 71.4 | 68.7 | 74.2 | 71.2 | 69.0 | 74.0 | 71.0 | 68.7 |
| 4 Min.... | 71.1 | 70.5 | 69.8 | 70.2 | 70.0 | 69.4 | 72.7 | 71.0 | 68.3 | 70.8 | 70.5 | 69.4 | 73.4 | 70.4 | 67.8 |
| 5 Max... | 77.1 | 74.0 | 70.3 | 77.3 | 73.9 | 70.2 | 75.1 | 71.6 | 69.6 | 75.2 | 71.2 | 69.9 | 74.8 | 71.2 | 69.0 |
| 5 Min.... | 71.2 | 71.3 | 69.8 | 70.2 | 70.6 | 69.5 | 72.4 | 71.1 | 68.8 | 71.2 | 70.4 | 69.4 | 72.9 | 71.0 | 68.9 |
| 6 Max... | 77.5 | 73.9 | 70.5 | 79.0 | 74.0 | 70.2 | 75.3 | 71.7 | 69.0 | 76.9 | 71.4 | 70.9 | 74.8 | 71.0 | 69.4 |
| 6 Min.... | 71.2 | 71.3 | 70.2 | 70.0 | 70.6 | 69.6 | 72.5 | 71.3 | 69.0 | 70.0 | 71.0 | 69.7 | 73.3 | 71.4 | 69.3 |
| 7 Max... | 78.5 | 73.7 | 71.2 | 79.8 | 74.8 | 70.8 | 76.9 | 72.1 | 69.4 | 76.3 | 72.0 | 70.3 | 75.4 | 72.0 | 69.9 |
| 7 Min.... | 71.8 | 71.4 | 70.8 | 71.0 | 71.0 | 70.2 | 72.9 | 72.0 | 69.1 | 71.3 | 71.5 | 70.1 | 74.4 | 72.0 | 69.4 |
| 9 Max... | 78.6 | 74.3 | 71.2 | 79.2 | 74.6 | 70.8 | 75.5 | 72.3 | 69.4 | 76.8 | 71.8 | 70.4 | 76.0 | 72.1 | 70.0 |
| 9 Min.... | 72.2 | 71.4 | 70.0 | 71.2 | 70.3 | 69.7 | 72.4 | 71.1 | 68.8 | 72.1 | 70.8 | 69.3 | 73.2 | 71.4 | 69.4 |
| 10 Max... | 79.8 | 75.6 | 72.2 | 79.8 | 75.3 | 71.9 | 76.8 | 73.2 | 70.1 | 77.4 | 73.0 | 71.1 | 76.0 | 73.0 | 70.7 |
| 10 Min.... | 73.1 | 72.8 | 71.6 | 71.9 | 71.7 | 71.1 | 73.7 | 72.8 | 70.0 | 72.0 | 72.2 | 71.0 | 74.8 | 72.7 | 70.2 |
| 11 Max... | 73.7 | 73.7 | 72.7 | 73.6 | 72.7 | 72.2 | 75.0 | 73.6 | 70.8 | 74.0 | 73.1 | 71.5 | 76.2 | 75.1 | 71.1 |
| 11 Min.... | 72.7 | 72.4 | 71.8 | 71.4 | 71.4 | 71.0 | 73.6 | 73.0 | 70.5 | 72.9 | 72.3 | 71.3 | 73.3 | 73.2 | 70.6 |
| 12 Max... | 71.6 | 69.6 | 69.8 | 71.7 | 68.7 | 69.3 | 69.8 | 71.4 | 70.2 | 70.5 | 76.8 | 70.9 | 72.6 | 72.3 | 71.0 |
| 12 Min.... | 64.4 | 66.0 | 68.0 | 62.8 | 65.4 | 67.4 | 67.1 | 69.2 | 69.2 | 66.3 | 69.0 | 69.3 | 69.9 | 71.7 | 70.9 |
| 13 Max... | 70.7 | 68.8 | 68.1 | 71.1 | 68.3 | 67.8 | 69.2 | 69.3 | 68.5 | 69.8 | 68.8 | 68.8 | 69.0 | 70.4 | 70.2 |
| 13 Min.... | 65.0 | 65.9 | 67.1 | 63.6 | 65.3 | 66.9 | 66.9 | 68.0 | 67.8 | 66.0 | 67.8 | 67.8 | 68.3 | 70.1 | 70.0 |
| 14 Max... | 68.0 | 67.1 | 67.3 | 67.8 | 66.7 | 67.2 | 68.9 | 66.2 | 67.0 | 66.1 | 66.0 | 67.8 | 68.9 | 69.0 | 69.0 |
| 14 Min.... | 65.8 | 66.0 | 66.4 | 65.2 | 65.6 | 66.3 | 66.6 | 67.5 | 66.4 | 66.4 | 67.0 | 67.1 | 67.8 | 68.6 | 68.3 |
| 16 Max... | 67.1 | 65.7 | 66.3 | 66.1 | 65.6 | 66.0 | 66.0 | 67.0 | 66.3 | 66.7 | 66.5 | 66.5 | 67.0 | 68.0 | 67.9 |
| 16 Min.... | 62.3 | 63.2 | 65.0 | 61.5 | 63.0 | 64.8 | 64.0 | 65.6 | 65.6 | 63.5 | 65.2 | 65.6 | 65.5 | 67.0 | 67.2 |
| 17 Max... | 62.6 | 63.7 | 65.4 | 62.3 | 63.5 | 65.3 | 64.4 | 66.6 | 65.5 | 63.9 | 65.6 | 66.0 | 66.1 | 67.5 | 67.3 |
| 17 Min.... | 61.6 | 62.7 | 64.3 | 60.9 | 62.6 | 64.3 | 63.5 | 64.9 | 65.1 | 62.9 | 64.4 | 65.2 | 64.7 | 66.4 | 66.8 |
| 18 Max... | 62.7 | 65.0 | 65.2 | 62.4 | 63.6 | 63.8 | 63.9 | 64.3 | 64.5 | 64.6 | 63.9 | 64.5 | 64.0 | 65.6 | 66.5 |
| 18 Min.... | 59.3 | 62.3 | 63.5 | 60.0 | 62.4 | 63.3 | 62.9 | 63.8 | 64.0 | 62.7 | 63.5 | 64.0 | 63.6 | 65.0 | 65.9 |
| 19 Max... | 60.8 | 61.4 | 63.6 | 60.1 | 61.2 | 63.8 | 61.8 | 63.8 | 63.9 | 60.7 | 63.8 | 64.5 | 63.4 | 65.1 | 65.8 |
| 19 Min.... | 58.9 | 60.3 | 62.0 | 58.4 | 60.2 | 62.2 | 60.4 | 62.8 | 63.4 | 59.6 | 62.1 | 62.9 | 61.9 | 64.1 | 65.4 |
| 20 Max... | 61.6 | 60.4 | 61.9 | 62.0 | 60.8 | 62.0 | 60.3 | 62.0 | 63.1 | 60.6 | 61.7 | 62.8 | 60.9 | 63.5 | 64.8 |
| 20 Min.... | 57.8 | 58.9 | 60.3 | 56.6 | 58.6 | 60.7 | 58.8 | 60.7 | 61.8 | 58.6 | 60.1 | 61.4 | 59.7 | 62.3 | 64.2 |
| 21 Max... | 65.1 | 62.5 | 61.9 | 66.9 | 63.8 | 61.6 | 62.8 | 61.8 | 61.6 | 63.9 | 61.7 | 61.8 | 61.3 | 62.0 | 63.0 |
| 21 Min.... | 59.4 | 59.6 | 60.6 | 58.9 | 59.6 | 61.1 | 59.4 | 60.7 | 61.3 | 59.5 | 60.6 | 61.4 | 60.3 | 61.6 | 62.6 |
| 23 Max... | 64.0 | 61.8 | 62.3 | 63.8 | 61.7 | 62.3 | 61.3 | 62.4 | 62.5 | 64.0 | 62.2 | 62.8 | 61.3 | 62.5 | 63.4 |
| 23 Min.... | 57.3 | 58.5 | 60.8 | 56.4 | 57.8 | 60.6 | 58.1 | 60.8 | 61.6 | 57.8 | 60.4 | 61.4 | 59.0 | 61.6 | 62.8 |
| 24 Max... | 62.1 | 60.5 | 61.1 | 62.0 | 60.2 | 60.6 | 60.1 | 61.0 | 61.1 | 60.8 | 61.0 | 61.2 | 59.9 | 60.7 | 62.1 |
| 24 Min.... | 57.7 | 57.4 | 60.4 | 56.5 | 58.5 | 59.9 | 58.5 | 59.8 | 60.5 | 58.4 | 59.5 | 60.3 | 58.8 | 60.4 | 61.7 |
| 25 Max... | 61.9 | 60.7 | 61.2 | 63.1 | 60.6 | 61.4 | 62.5 | 60.9 | 60.8 | 63.8 | 60.9 | 61.1 | 61.0 | 60.8 | 61.0 |
| 25 Min.... | 60.3 | 60.5 | 60.8 | 59.8 | 60.4 | 60.6 | 60.4 | 60.6 | 60.6 | 60.7 | 60.7 | 60.8 | 60.2 | 60.6 | 61.5 |
| 26 Max... | 61.8 | 61.9 | 62.4 | 62.2 | 62.0 | 62.6 | 62.0 | 62.2 | 61.7 | 61.9 | 62.6 | 62.2 | 62.1 | 61.7 | 61.9 |
| 26 Min.... | 59.3 | 60.5 | 61.7 | 59.0 | 60.1 | 61.6 | 60.3 | 61.5 | 61.3 | 60.2 | 61.3 | 62.0 | 60.8 | 61.4 | 61.9 |
| 27 Max... | 57.0 | 57.9 | 60.8 | 56.3 | 57.2 | 60.7 | 57.4 | 60.7 | 61.1 | 56.6 | 60.6 | 61.0 | 56.3 | 60.9 | 62.0 |
| 27 Min.... | 54.4 | 55.0 | 58.4 | 52.5 | 54.6 | 58.0 | 55.0 | 57.5 | 59.6 | 54.5 | 57.4 | 59.4 | 55.1 | 59.5 | 60.5 |
| 28 Max... | 53.5 | 55.3 | 58.0 | 52.8 | 55.2 | 58.2 | 55.4 | 58.0 | 59.3 | 55.0 | 57.9 | 59.0 | 56.0 | 59.5 | 61.2 |
| 28 Min.... | 53.2 | 54.6 | 57.0 | 52.5 | 54.7 | 57.4 | 54.2 | 56.9 | 58.8 | 53.8 | 56.5 | 58.4 | 54.9 | 58.8 | 60.6 |
| 30 Max... | 53.4 | 53.3 | 54.5 | 53.7 | 53.4 | 55.0 | 52.4 | 54.6 | 56.4 | 53.2 | 54.1 | 56.0 | 52.0 | 55.7 | 58.7 |
| 30 Min.... | 48.7 | 51.5 | 54.4 | 47.6 | 51.0 | 54.8 | 51.0 | 54.3 | 56 1 | 50.1 | 53.9 | 55.6 | 51.8 | 55.6 | 58.4 |
| Monthly range.... | 4.36 | 1.71 | 1.00 | 5.56 | 2.48 | 0.97 | 2.11 | 0.96 | 0.56 | 3.24 | 1.08 | 0.71 | 1.47 | 0.64 | 0.40 |

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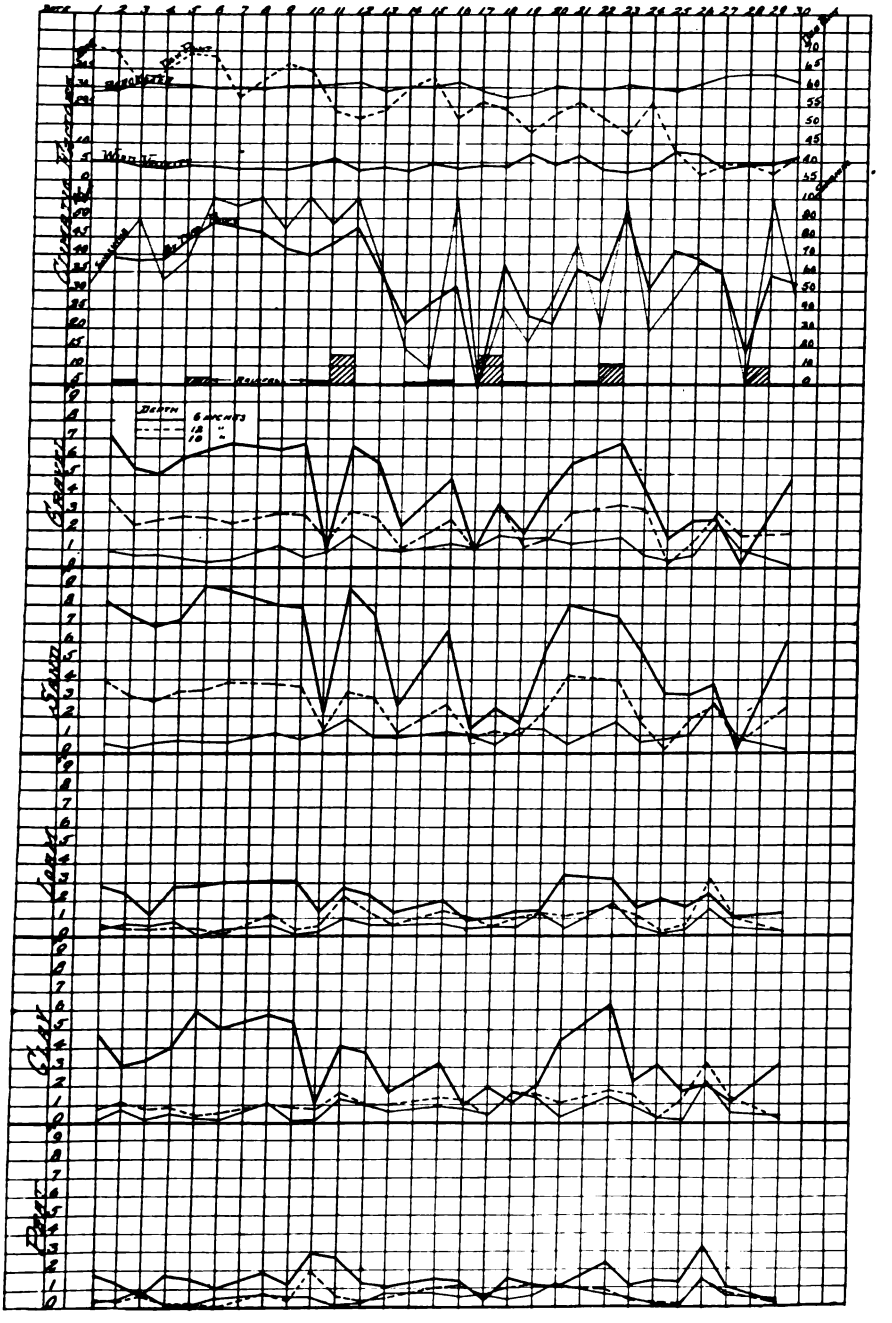


FIG. 25.

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TABLE 40.—DAILY MAXIMUM AND MINIMUM TEMPERATURES OF DIFFERENT TYPES OF SOIL, OCTOBER, 1912.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 57.6 | 55.0 | 54.7 | 57.8 | 55.4 | 55.0 | 54.2 | 54.1 | 55.5 | 55.8 | 54.0 | 55.5 | 52.3 | 54.9 | 56.5 |
| 1 Min. | 49.3 | 51.6 | 54.4 | 48.6 | 51.6 | 54.7 | 51.2 | 53.7 | 55.3 | 50.4 | 53.4 | 55.2 | 51.4 | 54.7 | 57.6 |
| 2 Max. | 58.0 | 55.8 | 56.1 | 58.8 | 55.8 | 55.4 | 54.5 | 54.3 | 55.3 | 56.6 | 54.6 | 55.4 | 52.40 | 54.8 | 56.1 |
| 2 Min. | 50.3 | 52.2 | 54.9 | 49.4 | 52.2 | 55.0 | 51.7 | 54.0 | 55.2 | 51.5 | 54.1 | 55.3 | 51.6 | 54.3 | 56.9 |
| 3 Max. | 54.4 | 54.8 | 55.1 | 53.7 | 54.3 | 55.7 | 53.6 | 54.7 | 55.4 | 53.6 | 54.0 | 55.8 | 53.1 | 54.8 | 56.0 |
| 3 Min. | 52.3 | 53.8 | 54.9 | 52.2 | 53.6 | 55.2 | 53.0 | 54.5 | 55.2 | 52.8 | 54.6 | 55.4 | 52.3 | 54.1 | 56.2 |
| 5 Max. | 60.3 | 58.0 | 56.4 | 62.2 | 58.9 | 56.7 | 57.5 | 55.8 | 55.9 | 56.9 | 55.9 | 56.1 | 55.0 | 54.9 | 59.8 |
| 5 Min. | 52.2 | 54.5 | 55.6 | 51.5 | 54.1 | 55.9 | 52.8 | 53.9 | 55.4 | 53.4 | 55.0 | 55.6 | 53.8 | 54.4 | 56.0 |
| 7 Max. | 60.3 | 59.4 | 58.3 | 60.8 | 59.1 | 58.4 | 59.0 | 57.6 | 56.8 | 59.0 | 58.1 | 57.4 | 58.0 | 55.7 | 56.8 |
| 7 Min. | 58.2 | 58.1 | 58.1 | 58.0 | 58.2 | 58.1 | 57.9 | 57.5 | 56.3 | 58.4 | 57.8 | 57.3 | 57.5 | 55.5 | 56.1 |
| 8 Max. | 53.8 | 55.1 | 57.5 | 53.0 | 54.4 | 57.4 | 54.8 | 57.8 | 57.4 | 54.1 | 57.4 | 57.8 | 55.7 | 56.5 | 57.3 |
| 8 Min. | 52.3 | 54.5 | 56.4 | 51.5 | 53.4 | 55.9 | 53.5 | 56.2 | 56.8 | 53.6 | 55.9 | 57.0 | 54.0 | 56.3 | 56.7 |
| 9 Max. | 54.3 | 53.7 | 54.0 | 54.4 | 53.5 | 54.4 | 53.4 | 54.8 | 55.7 | 54.1 | 54.3 | 55.4 | 52.8 | 55.3 | 56.7 |
| 9 Min. | 49.9 | 51.4 | 52.0 | 49.4 | 51.0 | 54.3 | 51.3 | 53.9 | 55.1 | 51.1 | 53.5 | 54.8 | 51.7 | 54.5 | 56.0 |
| 10 Max. | 54.2 | 54.4 | 55.1 | 54.4 | 54.3 | 55.4 | 54.2 | 54.8 | 55.2 | 54.1 | 54.8 | 55.3 | 54.0 | 54.9 | 56.6 |
| 10 Min. | 53.4 | 53.9 | 54.8 | 53.1 | 53.9 | 54.9 | 53.4 | 54.7 | 55.0 | 53.4 | 54.4 | 55.0 | 53.4 | 54.6 | 56.2 |
| 11 Max. | 56.6 | 56.2 | 55.0 | 57.9 | 56.0 | 55.2 | 55.9 | 54.8 | 55.1 | 56.8 | 54.8 | 55.0 | 54.4 | 54.8 | 56.2 |
| 11 Min. | 54.0 | 54.2 | 54.9 | 53.8 | 54.6 | 55.1 | 53.8 | 54.6 | 54.9 | 54.3 | 54.5 | 54.9 | 54.0 | 54.5 | 56.0 |
| 12 Max. | 57.4 | 57.3 | 56.8 | 57.1 | 57.4 | 57.0 | 57.9 | 56.5 | 55.9 | 57.5 | 56.8 | 57.3 | 57.3 | 56.3 | 57.2 |
| 12 Min. | 54.9 | 54.8 | 55.6 | 54.3 | 55.0 | 55.8 | 54.7 | 54.9 | 55.4 | 54.6 | 55.4 | 55.3 | 55.1 | 54.8 | 55.6 |
| 15 Max. | 52.4 | 51.3 | 52.1 | 52.7 | 51.7 | 53.0 | 50.5 | 51.9 | 53.2 | 51.8 | 51.7 | 53.0 | 49.8 | 52.9 | 55.2 |
| 15 Min. | 46.7 | 49.0 | 51.8 | 46.8 | 49.3 | 52.4 | 48.7 | 51.3 | 52.9 | 48.8 | 51.2 | 52.7 | 49.4 | 52.6 | 54.8 |
| 16 Max. | 50.8 | 49.8 | 56.8 | 51.2 | 49.0 | 51.4 | 48.0 | 50.1 | 51.7 | 49.3 | 50.0 | 51.8 | 48.0 | 50.9 | 54.5 |
| 16 Min. | 44.4 | 46.7 | 50.1 | 44.7 | 47.4 | 50.6 | 45.9 | 49.7 | 51.6 | 45.7 | 49.4 | 51.3 | 47.0 | 50.6 | 53.7 |
| 17 Max. | 53.0 | 51.4 | 56.9 | 53.7 | 51.4 | 51.7 | 50.1 | 50.3 | 51.4 | 51.2 | 49.6 | 51.2 | 47.9 | 50.4 | 53.4 |
| 17 Min. | 45.5 | 47.4 | 50.0 | 44.9 | 47.7 | 50.4 | 46.9 | 49.6 | 51.3 | 46.7 | 49.4 | 51.1 | 47.0 | 50.1 | 53.0 |
| 18 Max. | 54.9 | 53.4 | 52.7 | 55.1 | 53.8 | 52.8 | 51.8 | 52.7 | 52.2 | 53.7 | 51.9 | 52.1 | 50.9 | 50.7 | 53.0 |
| 18 Min. | 50.9 | 50.4 | 51.6 | 50.7 | 51.0 | 51.7 | 49.9 | 50.1 | 51.3 | 50.3 | 49.9 | 51.3 | 48.7 | 49.9 | 52.9 |
| 19 Max. | 51.4 | 52.7 | 52.4 | 51.9 | 52.9 | 52.5 | 51.9 | 52.3 | 52.3 | 51.8 | 52.8 | 52.6 | 51.6 | 50.8 | 52.9 |
| 19 Min. | 48.1 | 49.1 | 50.4 | 48.3 | 51.0 | 51.4 | 51.1 | 50.4 | 51.6 | 50.3 | 51.1 | 51.9 | 50.3 | 50.2 | 52.3 |
| 21 Max. | 53.3 | 51.3 | 51.3 | 53.8 | 51.7 | 51.6 | 51.0 | 50.7 | 52.0 | 51.9 | 50.6 | 51.8 | 49.1 | 51.0 | 53.4 |
| 21 Min. | 46.9 | 48.5 | 50.4 | 46.0 | 48.5 | 51.1 | 50.2 | 48.0 | 51.5 | 47.9 | 50.0 | 51.4 | 48.5 | 50.8 | 53.2 |
| 22 Max. | 54.0 | 54.2 | 54.5 | 54.1 | 54.3 | 54.0 | 52.7 | 53.8 | 52.3 | 53.1 | 52.9 | 52.7 | 52.8 | 51.0 | 52.9 |
| 22 Min. | 52.8 | 52.0 | 51.6 | 53.5 | 52.0 | 51.9 | 50.8 | 51.4 | 51.7 | 52.1 | 50.8 | 51.3 | 50.2 | 50.0 | 52.1 |
| 23 Max. | 48.5 | 51.0 | 52.7 | 48.1 | 51.2 | 51.4 | 52.0 | 50.2 | 52.0 | 49.8 | 52.1 | 52.3 | 50.9 | 50.9 | 52.1 |
| 23 Min. | 46.0 | 47.4 | 49.7 | 45.7 | 47.4 | 49.9 | 46.9 | 48.9 | 50.7 | 46.7 | 49.2 | 50.1 | 47.9 | 49.2 | 50.9 |
| 24 Max. | 47.4 | 47.7 | 49.9 | 47.5 | 47.6 | 50.0 | 49.9 | 48.9 | 52.1 | 48.9 | 49.4 | 51.6 | 48.7 | 51.2 | 52.4 |
| 24 Min. | 42.8 | 45.4 | 49.1 | 42.0 | 45.7 | 49.6 | 46.7 | 45.1 | 51.2 | 44.3 | 48.5 | 50.4 | 46.9 | 50.0 | 51.9 |
| 25 Max. | 47.8 | 46.9 | 48.6 | 48.5 | 47.2 | 49.1 | 46.4 | 47.9 | 50.5 | 48.9 | 48.1 | 50.2 | 48.2 | 50.1 | 52.2 |
| 25 Min. | 42.0 | 44.1 | 47.6 | 41.7 | 44.2 | 48.1 | 45.8 | 43.5 | 49.7 | 43.1 | 47.5 | 49.0 | 45.5 | 49.5 | 51.9 |
| 26 Max. | 48.5 | 47.6 | 48.3 | 49.1 | 48.0 | 49.0 | 48.3 | 47.8 | 49.5 | 47.5 | 47.5 | 49.0 | 45.5 | 48.8 | 51.5 |
| 26 Min. | 42.7 | 45.1 | 47.9 | 42.3 | 45.3 | 48.7 | 44.2 | 47.0 | 49.1 | 44.1 | 47.1 | 48.6 | 45.1 | 48.3 | 51.0 |
| 28 Max. | 50.0 | 49.0 | 48.7 | 51.3 | 49.2 | 49.6 | 47.8 | 47.4 | 48.9 | 49.1 | 47.6 | 48.7 | 48.9 | 47.4 | 50.0 |
| 28 Min. | 44.8 | 45.8 | 47.6 | 44.1 | 45.5 | 48.0 | 44.4 | 46.7 | 48.2 | 44.8 | 46.8 | 47.9 | 44.1 | 46.8 | 49.7 |
| 29 Max. | 51.1 | 50.1 | 49.8 | 51.5 | 50.1 | 50.0 | 48.7 | 48.8 | 49.4 | 49.9 | 48.8 | 49.4 | 47.1 | 47.7 | 49.8 |
| 29 Min. | 46.8 | 47.9 | 48.9 | 46.5 | 48.0 | 49.2 | 46.8 | 47.8 | 48.4 | 46.9 | 47.9 | 48.5 | 46.1 | 47.0 | 49.7 |
| 30 Max. | 46.4 | 48.0 | 49.6 | 46.5 | 48.9 | 49.7 | 47.1 | 48.9 | 49.3 | 47.1 | 48.8 | 49.2 | 47.2 | 47.9 | 49.6 |
| 30 Min. | 45.2 | 46.7 | 48.9 | 44.4 | 46.5 | 48.9 | 45.9 | 48.0 | 49.1 | 45.9 | 48.1 | 49.0 | 46.5 | 47.7 | 49.3 |
| 31 Max. | 41.9 | 44.0 | 47.8 | 41.3 | 44.0 | 48.1 | 43.3 | 47.2 | 49.0 | 43.1 | 47.3 | 48.9 | 44.9 | 47.8 | 49.5 |
| 31 Min. | 41.3 | 43.5 | 46.5 | 40.2 | 43.2 | 46.9 | 42.5 | 46.2 | 48.6 | 42.4 | 45.9 | 47.9 | 43.8 | 47.2 | 49.3 |
| Monthly range | 4.25 | 2.41 | 0.66 | 4.84 | 2.45 | 0.76 | 2.29 | 1.31 | 0.52 | 2.84 | 0.91 | 0.70 | 1.29 | 0.66 | 0.56 |

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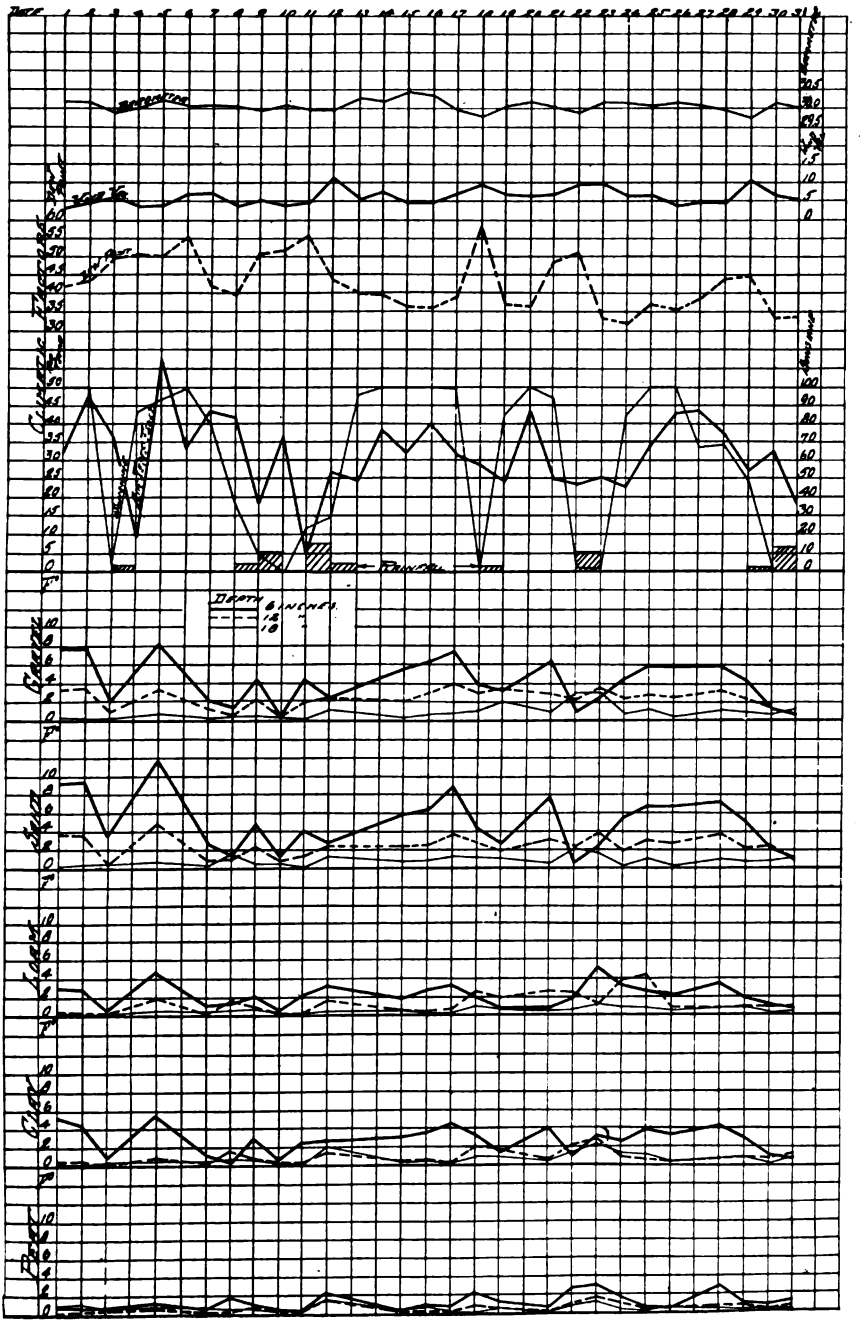


FIG. 26.

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TABLE 41.—DAILY MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOVEMBER, 1912.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 36.9 | 41.7 | 45.4 | 38.7 | 42.8 | 46.1 | 41.0 | 45.1 | 47.9 | 40.2 | 44.9 | 47.1 | 42.7 | 46.9 | 49.5 |
| 1 Min. | 37.8 | 40.6 | 44.3 | 37.2 | 40.2 | 44.9 | 39.4 | 44.0 | 47.1 | 39.2 | 43.8 | 46.0 | 41.3 | 46.1 | 49.2 |
| 2 Max. | 37.3 | 39.2 | 43.4 | 38.3 | 39.1 | 43.7 | 38.2 | 42.8 | 46.1 | 37.8 | 42.5 | 45.1 | 39.9 | 44.0 | 46.8 |
| 2 Min. | 36.4 | 38.7 | 42 8 | 36.0 | 38.9 | 43.1 | 37.7 | 42.1 | 45.4 | 34.6 | 41.9 | 44.3 | 39.0 | 44.0 | 46.2 |
| 4 Max. | 39.6 | 39.9 | 42.4 | 38.9 | 40.0 | 42.9 | 38.2 | 41.3 | 44.2 | 40.2 | 41.0 | 43.2 | 37.4 | 42.0 | 46.1 |
| 4 Min. | 37.0 | 38.5 | 41.8 | 36.8 | 38.8 | 42.5 | 37.0 | 40.5 | 43.6 | 36.8 | 40.8 | 42.9 | 37.1 | 41.4 | 45.4 |
| 5 Max. | 44.5 | 43.4 | 43.4 | 44.9 | 43.8 | 43.9 | 42.1 | 41.9 | 44.0 | 43.1 | 42.1 | 43.6 | 38.9 | 41.4 | 45.2 |
| 5 Min. | 40.5 | 41.3 | 43.2 | 40.4 | 41.9 | 43.8 | 39.9 | 41.8 | 43.5 | 39.9 | 41.9 | 43.2 | 38.5 | 40.8 | 44.5 |
| 6 Max. | 48.1 | 47.5 | 46.8 | 48.5 | 48.7 | 47.1 | 46.5 | 45.1 | 45.3 | 47.2 | 45.8 | 45.7 | 43.9 | 42.1 | 44.0 |
| 6 Min. | 46.6 | 46.0 | 45.4 | 46.7 | 46.2 | 45.9 | 44.6 | 43.9 | 44.3 | 45.5 | 44.3 | 44.4 | 42.1 | 41.6 | 44.4 |
| 7 Max. | 46.5 | 46.7 | 47.0 | 46.3 | 46.6 | 47.2 | 45.7 | 46.1 | 46.7 | 46.5 | 46.3 | 46.8 | 44.4 | 43.9 | 45.1 |
| 7 Min. | 44.9 | 45.6 | 47:0 | 44.8 | 45.7 | 47.1 | 44.9 | 45.9 | 45.7 | 45.2 | 46.2 | 46.3 | 44.3 | 43.0 | 44.6 |
| 8 Max. | 44.1 | 44.2 | 46.0 | 43.8 | 44.1 | 46.1 | 43.3 | 45.2 | 46.5 | 43.7 | 45.3 | 46.4 | 43.0 | 44.0 | 45.2 |
| 8 Min. | 41.7 | 43.0 | 45.5 | 41.6 | 43.0 | 45.5 | 42.1 | 44.4 | 46.0 | 42.1 | 44.5 | 45.9 | 42.0 | 43.8 | 45.1 |
| 9 Max. | 42.8 | 43.2 | 45.3 | 42.9 | 43.8 | 45.9 | 42.3 | 44.7 | 46.3 | 42.6 | 44.0 | 46.0 | 42.3 | 44.1 | 46.0 |
| 9 Min. | 41.3 | 42.9 | 44.9 | 41.2 | 43.1 | 45.4 | 41.9 | 44.1 | 45.9 | 41.9 | 44.1 | 45.3 | 41.9 | 43.9 | 45.9 |
| 11 Max. | 48.0 | 46.3 | 45.3 | 48.8 | 46.4 | 45.8 | 45.2 | 44.3 | 45.9 | 46.4 | 44.3 | 45.8 | 42.8 | 43.4 | 46.0 |
| 11 Min. | 43.3 | 43.8 | 44.8 | 43.0 | 43.9 | 45.0 | 42.8 | 43.9 | 44.9 | 42.8 | 43.9 | 44.7 | 41.9 | 42.9 | 45.2 |
| 12 Max. | 51.0 | 49.8 | 47.9 | 51.3 | 49 8 | 48.1 | 48.9 | 47.2 | 46.4 | 49.9 | 47.4 | 46.8 | 46.7 | 44.5 | 45.9 |
| 12 Min. | 48.6 | 48.1 | 46.9 | 48.9 | 48.1 | 46.8 | 47.3 | 46.2 | 45.9 | 47.0 | 46.4 | 46.1 | 45.4 | 43.9 | 45.5 |
| 13 Max. | 51.3 | 50.0 | 49.8 | 51.3 | 50.5 | 49.6 | 50.4 | 49.8 | 48.0 | 51.9 | 49.8 | 49.2 | 49.1 | 47.0 | 46.7 |
| 13 Min. | 49.2 | 50.0 | 49.0 | 48 7 | 49.9 | 49.0 | 49.9 | 48.5 | 47.1 | 49.9 | 48.8 | 47.9 | 48.2 | 45.3 | 46 2 |
| 14 Max. | 42.9 | 45.2 | 46.2 | 42.0 | 45.0 | 41.8 | 45.0 | 47.9 | 48.4 | 44.3 | 47.8 | 48.5 | 46.3 | 46.0 | 46.5 |
| 14 Min. | 40.2 | 43.0 | 46.8 | 39.6 | 42.8 | 46.8 | 42.4 | 46.6 | 48.2 | 41.9 | 46.3 | 47.9 | 44.2 | 46.9 | 46.5 |
| 15 Max. | 38.4 | 40.9 | 45.0 | 38.1 | 41.0 | 45.3 | 40.1 | 44.7 | 47.2 | 39.4 | 44.2 | 46.5 | 42.5 | 46.4 | 47.0 |
| 15 Min. | 37.4 | 39.9 | 44.2 | 37.0 | 40.2 | 44.6 | 39.2 | 43.7 | 46.7 | 38.7 | 43.0 | 45.3 | 41.4 | 45.4 | 47.9 |
| 16 Max. | 36.8 | 39.1 | 43.3 | 36.3 | 39.3 | 43.8 | 38.0 | 42.5 | 45.3 | 37.6 | 42.1 | 44.4 | 40.0 | 44.6 | 47.9 |
| 16 Min. | 35.3 | 37.9 | 42.3 | 35.1 | 38.3 | 42.7 | 36.7 | 41.4 | 44.4 | 36.4 | 40.8 | 43.2 | 38.7 | 43.2 | 46.3 |
| 18 Max. | 39.7 | 39.9 | 42.0 | 39.1 | 39.9 | 42.5 | 38.0 | 40.5 | 43.0 | 38.8 | 49.5 | 42.4 | 37.8 | 41.3 | 44.5 |
| 18 Min. | 36.9 | 38.4 | 41.8 | 36.2 | 38.5 | 42.1 | 37.0 | 40.1 | 42.8 | 37.1 | 40.1 | 42.2 | 37.5 | 40.9 | 44.2 |
| 19 Max. | 41.2 | 41.0 | 42.0 | 41.2 | 41.0 | 42.4 | 39.0 | 40.6 | 42.8 | 39.9 | 46.6 | 42.3 | 37.9 | 46.5 | 44.0 |
| 19 Min. | 37.5 | 38.9 | 41.8 | 37.2 | 38.9 | 42.1 | 37.4 | 40.2 | 42.7 | 37.8 | 40.3 | 42.0 | 37.4 | 40.2 | 43.9 |
| 20 Max. | 41.4 | 39.7 | 42.3 | 41.5 | 39.8 | 42.5 | 38.7 | 40.9 | 42.8 | 39.3 | 41.2 | 42.4 | 38.3 | 40.5 | 43.5 |
| 20 Min. | 37.8 | 39.0 | 41.9 | 37.3 | 39.0 | 42.3 | 37.9 | 40.8 | 41.7 | 37.9 | 40.9 | 42.3 | 38.1 | 40.3 | 43.4 |
| 21 Max. | 42.3 | 41.7 | 42.6 | 42.5 | 41.9 | 42.9 | 41.0 | 41.5 | 42.6 | 41.0 | 42.6 | 42.6 | 39.9 | 46.2 | 42.9 |
| 21 Min. | 40.5 | 41.1 | 42.0 | 40 5 | 41.4 | 42.4 | 39.9 | 40.5 | 41.9 | 40.0 | 40.9 | 41.6 | 38.4 | 39.3 | 42.3 |
| 22 Max. | 39.9 | 40.4 | 42.5 | 39.8 | 40.9 | 42.8 | 39.4 | 41.6 | 43.0 | 39.5 | 41.8 | 42.8 | 39.4 | 46.0 | 42.9 |
| 22 Min. | 37.4 | 39.2 | 42.2 | 37.0 | 39 6 | 42 6 | 38.4 | 41.3 | 42.8 | 38.1 | 41.4 | 42.6 | 38.9 | 40.4 | 42 7 |
| 23 Max. | 37.2 | 38.7 | 41.8 | 37.1 | 38.9 | 42.0 | 37.6 | 40.8 | 42.5 | 37.4 | 49.7 | 42.3 | 38.2 | 40.5 | 43.9 |
| 23 Min. | 36.6 | 38.4 | 41.4 | 36.4 | 38 8 | 41.9 | 37.3 | 40.4 | 42.5 | 37.3 | 40.3 | 42.1 | 38.0 | 40.5 | 42.9 |
| 25 Max. | 35.9 | 37.5 | 40.3 | 35.5 | 37.7 | 40.8 | 36.0 | 39.1 | 41.8 | 38.2 | 39.9 | 41.1 | 38.7 | 39.9 | 42.8 |
| 25 Min. | 35.8 | 37.2 | 39.9 | 35.3 | 37.4 | 40 7 | 35.9 | 38.9 | 41.5 | 35.9 | 38.9 | 40.9 | 36.6 | 39.6 | 42.7 |
| 26 Max. | 34.8 | 36.4 | 39.2 | 34.3 | 36.6 | 39.9 | 35.0 | 38.1 | 49.7 | 35.0 | 38.0 | 39.9 | 35.7 | 38.7 | 42.0 |
| 26 Min. | 34.6 | 36.2 | 39 0 | 34.1 | 36.4 | 39.5 | 34.9 | 37.9 | 40 5 | 35.0 | 37.8 | 39.9 | 35.6 | 38.5 | 41.9 |
| 27 Max. | 34.9 | 36.3 | 39.0 | 34.6 | 36.4 | 39.5 | 34.9 | 37.9 | 40.4 | 35.0 | 37.9 | 39.8 | 35.6 | 38.5 | 41.7 |
| 27 Min. | 34.8 | 36.3 | 38.9 | 34.4 | 36.4 | 39.4 | 34.8 | 37.8 | 40.2 | 34.8 | 37.6 | 39.4 | 35.4 | 38.3 | 41.5 |
| 29 Max. | 35.5 | 36.8 | 39.5 | 35.0 | 38.0 | 40.0 | 35.4 | 38.2 | 41.8 | 35.6 | 38.1 | 39.9 | 35.9 | 38.0 | 42.9 |
| 29 Min. | 35 4 | 36.6 | 39.3 | 35.0 | 37.0 | 39.8 | 35.3 | 38.1 | 40.8 | 35.3 | 37.9 | 39.8 | 35.8 | 38.5 | 41.6 |
| 30 Max. | 35.1 | 36.5 | 39.1 | 34.8 | 36.7 | 39.6 | 35.0 | 37.6 | 40.5 | 35.4 | 38.1 | 39.5 | 35.5 | 38.2 | 41.3 |
| 30 Min. | 34.6 | 36.2 | 38 4 | 34.2 | 36.2 | 39.2 | 34.6 | 37.3 | 39.8 | 34.7 | 37.4 | 39.0 | 34.8 | 37.6 | 40.8 |
| Monthly range | 1.85 | 1.04 | 0.56 | 1.97 | 1.13 | 0.39 | 1.03 | 0.62 | 0.59 | 1.50 | 0.63 | 9.59 | 0.73 | 0.53 | 0.37 |

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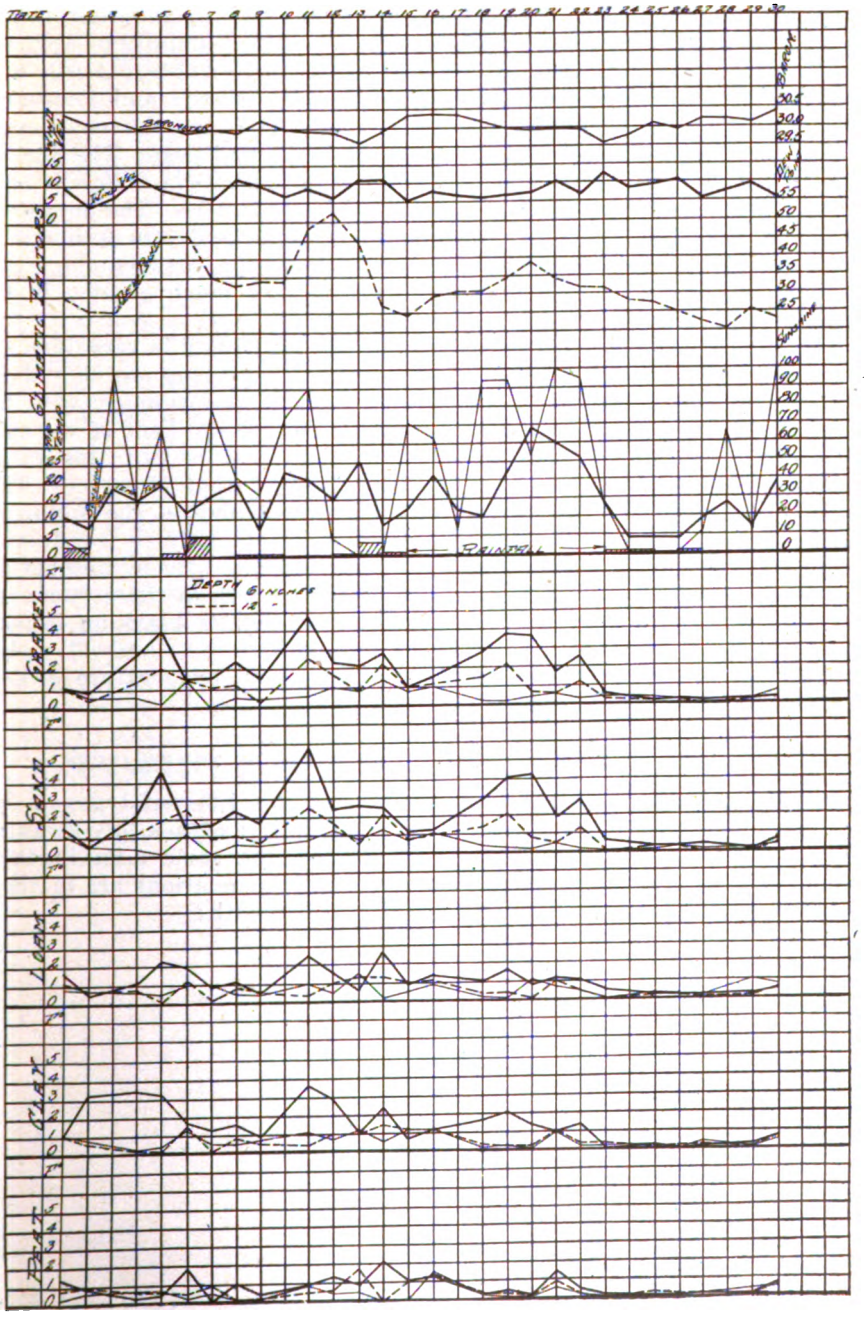


FIG. 27.

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The above tables (30-41) with their respective charts, show the following main facts: (1) the daily temperature of all the soils at all three depths fluctuated throughout the year, but in different degree during the different months. The greatest monthly amplitude occurred in June and was followed in order by May, July, August, April, September, October, November, December, January, March and February; (2) sand showed the greatest amplitude for the 6 and 12 inch depths and was followed in order by gravel, clay, loam, and peat. The fluctuation at the 18 inch depth was about the same for all the different soils with a slight difference in favor of the sand and gravel. The amplitude of the 6 inch depth was the greatest in all soils and was followed in order by the 12 and 18 inch depths. The variation between the 6 and 12 inch and the 6 and 18 inch depths were very much greater in the lighter soils than in the heavier soils.

The small soil temperature fluctuation in the winter is very interesting and needs special attention. Theoretically speaking we should expect a greater fluctuation in the winter than in the summer, with the same variation in air temperature, because the specific heat of the soils in summer is close to 0.5, while in the winter it is half this value, because the specific heat of ice is about half of that of water. This smaller amplitude in the winter may be attributed to the following chief causes: (1) in the winter the soil is heated only by conduction while in the summer it is heated by conduction and also by absorption, hence, the temperature is raised to a higher degree in the latter case, and the gradient is higher; (2) the latent heat of ice plays an important part in keeping the magnitude of fluctuations low; and (3) when the soil is covered with a thick layer of snow, its temperature is kept quite steady and varies but slightly.

### SEASONAL AND YEARLY AVERAGE AND RANGE OF TEMPERATURE.

On the preceding pages the temperature of the different types of soil has been considered from the standpoint of daily and monthly averages and ranges. It will now be well to present the same data in these forms, by season and year, and thus see what the relations are in these longer periods of time. The data are shown herewith:

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TABLE 42.—SEASONAL AND YEARLY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL.

| Season. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Winter: | | | | | | | | | | | | | | | |
| Dec..... | 33.50 | 34.83 | 36.87 | 33.29 | 34.84 | 37.16 | 33.27 | 35.41 | 37.40 | 33.55 | 35.52 | 36.98 | 32.32 | 34.35 | 37.13 |
| Jan..... | 26.24 | 28.14 | 30.93 | 24.62 | 28.27 | 31.44 | 26.60 | 29.68 | 32.10 | 26.40 | 29.27 | 31.34 | 25.58 | 29.68 | 32.94 |
| Feb..... | 29.13 | 29.90 | 30.84 | 28.20 | 29.84 | 30.88 | 28.17 | 29.43 | 30.75 | 28.41 | 29.52 | 30.39 | 29.15 | 29.31 | 31.27 |
| Ave..... | 29.62 | 30.96 | 32.88 | 28.70 | 30.96 | 33.16 | 29.35 | 31.51 | 33.42 | 29.45 | 31.44 | 32.90 | 29.02 | 31.11 | 33.78 |
| Spring: | | | | | | | | | | | | | | | |
| March.... | 29.91 | 30.43 | 31.04 | 30.13 | 30.72 | 31.42 | 29.46 | 30.13 | 30.72 | 29.87 | 30.35 | 30.83 | 28.36 | 30.02 | 31.13 |
| April..... | 41.81 | 40.70 | 39.27 | 41.46 | 40.04 | 38.92 | 39.16 | 37.47 | 36.58 | 40.20 | 38.44 | 37.48 | 34.04 | 35.48 | 31.89 |
| May..... | 56.07 | 54.41 | 52.03 | 56.11 | 54.08 | 52.0 | 55.07 | 53.02 | 50.62 | 56.00 | 53.43 | 51.96 | 55.61 | 52.00 | 50.44 |
| Ave..... | 42.60 | 41.85 | 40.78 | 42.57 | 41.61 | 40.78 | 41.23 | 40.21 | 39.31 | 42.02 | 40.74 | 40.09 | 39.34 | 39.17 | 37.72 |
| Summer: | | | | | | | | | | | | | | | |
| June..... | 67.25 | 65.33 | 62.61 | 66.52 | 64.39 | 62.08 | 66.28 | 63.88 | 61.00 | 66.51 | 63.89 | 62.24 | 67.15 | 64.24 | 61.64 |
| July..... | 72.56 | 71.11 | 69.16 | 71.74 | 70.20 | 68.49 | 72.40 | 70.55 | 67.86 | 72.20 | 70.15 | 68.74 | 73.30 | 68.56 | 68.70 |
| Aug..... | 68.00 | 67.18 | 66.33 | 67.85 | 66.85 | 66.07 | 67.82 | 67.00 | 65.52 | 68.01 | 66.92 | 66.23 | 68.60 | 67.22 | 66.26 |
| Ave..... | 69.27 | 67.87 | 66.03 | 68.70 | 67.15 | 65.55 | 68.63 | 67.14 | 64.79 | 68.91 | 69.69 | 65.74 | 69.68 | 66.67 | 65.53 |
| Autum: | | | | | | | | | | | | | | | |
| Sept..... | 65.40 | 65.20 | 65.33 | 65.08 | 64.88 | 65.08 | 65.76 | 65.82 | 65.08 | 65.56 | 65.56 | 65.45 | 66.37 | 66.44 | 66.08 |
| Oct ..... | 50.38 | 51.03 | 52.25 | 50.16 | 51.06 | 52.37 | 50.68 | 51.48 | 52.69 | 50.48 | 51.73 | 52.61 | 50.28 | 51.77 | 53.80 |
| Nov..... | 40.44 | 41.13 | 43.32 | 39.80 | 41.32 | 43.67 | 40.00 | 42.28 | 44.12 | 40.80 | 42.29 | 43.70 | 40.00 | 42.11 | 44.68 |
| Ave..... | 52.07 | 52.46 | 53.63 | 51.68 | 52.42 | 53.71 | 52.15 | 53.19 | 53.96 | 52.28 | 53.19 | 53.25 | 52.55 | 53.44 | 54.85 |
| Yearly Ave.. | 48.39 | 48.29 | 48.33 | 47.91 | 48.04 | 49.30 | 47.69 | 48.01 | 47.87 | 48.18 | 48.09 | 48.60 | 47.65 | 47.80 | 47.97 |

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TABLE 43.—SEASONAL AND YEARLY RANGE TEMPERATURE OF DIFFERENT TYPES OF SOIL.

| Season: | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Winter: | | | | | | | | | | | | | | | |
| Dec. | 1.31 | 0.92 | 0.64 | 1.09 | 0.75 | 0.60 | 0.66 | 0.62 | 0.60 | 0.69 | 0.72 | 0.64 | 0.60 | 0.61 | 0.60 |
| Jan. | 0.94 | 0.89 | 0.92 | 1.10 | 0.95 | 0.72 | 0.70 | 0.50 | 0.75 | 0.70 | 0.52 | 0.58 | 0.76 | 0.45 | 0.41 |
| Feb. | 0.42 | 0.37 | 0.41 | 0.63 | 0.48 | 0.46 | 0.46 | 0.37 | 0.42 | 0.47 | 0.44 | 0.32 | 0.43 | 0.39 | 0.36 |
| Ave. | 0.89 | 0.73 | 0.66 | 0.94 | 0.73 | 0.59 | 0.61 | 0.50 | 0.62 | 0.62 | 0.56 | 0.51 | 0.60 | 0.48 | 0.46 |
| Spring: | | | | | | | | | | | | | | | |
| March. | 0.58 | 0.53 | 0.44 | 0.57 | 0.57 | 0.51 | 0.59 | 0.57 | 0.58 | 0.43 | 0.43 | 0.84 | 0.47 | 0.46 | 0.43 |
| April. | 4.93 | 2.66 | 0.96 | 5.44 | 2.59 | 0.93 | 2.47 | 0.84 | 0.68 | 3.25 | 1.23 | 0.86 | 0.76 | 0.39 | 0.18 |
| May. | 6.59 | 3.18 | 0.83 | 7.76 | 3.28 | 0.47 | 2.92 | 0.78 | 0.52 | 4.14 | 0.97 | 0.59 | 1.81 | 0.98 | 0.62 |
| Ave. | 4.03 | 2.12 | 0.74 | 4.59 | 2.15 | 0.64 | 1.99 | 0.73 | 0.59 | 2.81 | 0.88 | 0.76 | 1.01 | 0.61 | 0.41 |
| Summer: | | | | | | | | | | | | | | | |
| June. | 7.56 | 3.32 | 0.92 | 8.43 | 3.32 | 0.95 | 3.09 | 0.87 | 0.47 | 4.56 | 0.90 | 0.56 | 1.62 | 0.48 | 0.44 |
| July. | 6.17 | 3.00 | 1.04 | 6.78 | 3.00 | 1.03 | 2.94 | 1.07 | 0.63 | 4.07 | 1.12 | 0.78 | 1.77 | 0.67 | 0.59 |
| Aug. | 5.22 | 2.63 | 1.08 | 6.59 | 2.95 | 1.26 | 2.56 | 3.31 | 0.60 | 3.47 | 1.12 | 0.70 | 1.34 | 0.75 | 0.51 |
| Ave. | 6.32 | 2.98 | 1.01 | 7.27 | 3.09 | 1.08 | 2.86 | 1.75 | 0.57 | 4.03 | 1.05 | 0.68 | 1.58 | 0.63 | 0.51 |
| Autumn: | | | | | | | | | | | | | | | |
| Sept. | 4.36 | 1.71 | 10.0 | 5.56 | 2.48 | 0.97 | 2.11 | 0.96 | 0.56 | 3.23 | 1.08 | 0.71 | 1.47 | 0.64 | 0.49 |
| Oct. | 4.25 | 2.41 | 0.96 | 4.84 | 2.45 | 0.78 | 2.20 | 1.31 | 0.52 | 2.84 | 0.91 | 0.70 | 1.20 | 0.60 | 0.56 |
| Nov. | 1.85 | 1.04 | 0.56 | 1.97 | 1.13 | 0.30 | 1.03 | 0.62 | 0.59 | 1.50 | 0.63 | 0.59 | 0.73 | 0.53 | 0.37 |
| Ave. | 3.49 | 1.72 | 0.84 | 4.12 | 2.02 | 0.68 | 1.78 | 0.96 | 0.56 | 2.52 | 0.87 | 0.67 | 1.13 | 0.59 | 0.47 |
| Yearly Range. | 3.66 | 1.89 | 0.81 | 4.23 | 2.89 | 0.75 | 1.61 | 0.99 | 0.59 | 2.45 | 0.64 | 0.86 | 1.06 | 0.81 | 0.46 |

The chief points brought out in the above tables (42-43) may be summarized thus: (1) the highest seasonal average temperature occurred in the summer followed in order by autumn, spring, and winter; (2) the greatest seasonal amplitude took place also in summer with autumn, spring, and winter coming next in order; (3) the average soil temperature of the autumnal equinox was higher than that of the spring; (4) the yearly average temperature was practically the same for all soils at all three depths; and (5) the yearly range was noticeably different: the sand shows the greatest amplitude and is followed in order by gravel, clay, loam, and peat respectively; the difference between the sand and peat is 3.15 for the 6 inch depth.

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## COMPARISON BETWEEN MONTHLY AVERAGE AND RANGE OF TEMPERATURE OF THE AIR AND THE SOILS.

It will be interesting now to compare the temperature of the air and of the different soils as to their average and range. The following tables contain these data:

TABLE 44.—COMPARISON BETWEEN THE MONTHLY AVERAGE TEMPERATURES OF THE AIR AND OF THE DIFFERENT TYPES OF SOIL.

| Soils. | December, 1911. | | | January, 1912. | | | February. | | | March. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Gravel | 33.50 | 34.83 | 36.87 | 26.24 | 28.14 | 30.93 | 29.13 | 29.90 | 30.84 | 29.91 | 30.43 | 31.04 |
| Sand | 33.29 | 34.84 | 37.16 | 24.62 | 28.27 | 31.44 | 28.20 | 29.84 | 30.88 | 30.13 | 30.72 | 31.42 |
| Loam | 33.27 | 35.41 | 37.40 | 26.60 | 29.68 | 32.10 | 28.17 | 29.43 | 30.75 | 29.46 | 30.13 | 30.72 |
| Clay | 33.55 | 35.52 | 36.98 | 26.40 | 29.27 | 31.34 | 28.41 | 29.52 | 30.39 | 29.87 | 30.35 | 30.83 |
| Peat | 32.32 | 34.35 | 37.13 | 25.58 | 29.68 | 32.94 | 28.15 | 29.31 | 31.27 | 28.36 | 30.02 | 31.13 |
| Air | 33.36 | | | 11.34 | | | 17.03 | | | 28.38 | | |

| Soils. | April. | | | May. | | | June. | | | July. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Gravel | 41.81 | 40.70 | 39.27 | 56.07 | 54.41 | 52.03 | 67.25 | 65.33 | 62.61 | 72.56 | 71.11 | 69.16 |
| Sand | 41.46 | 40.04 | 38.92 | 56.11 | 54.08 | 52.00 | 66.52 | 64.30 | 62.08 | 71.74 | 70.20 | 68.49 |
| Loam | 39.16 | 37.47 | 36.58 | 55.07 | 53.02 | 50.62 | 66.28 | 63.88 | 61.00 | 72.40 | 70.55 | 67.86 |
| Clay | 40.20 | 38.44 | 37.48 | 56.00 | 53.43 | 51.96 | 66.51 | 63.89 | 62.24 | 72.20 | 70.15 | 68.74 |
| Peat | 34.04 | 35.48 | 31.59 | 55.61 | 52.00 | 50.44 | 67.15 | 64.24 | 61.64 | 73.30 | 68.56 | 68.70 |
| Air | 50.22 | | | 62.00 | | | 70.78 | | | 75.77 | | |

| Soil. | August. | | | September. | | | October. | | | November. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Gravel | 68.00 | 67.18 | 66.33 | 65.40 | 65.20 | 65.33 | 50.38 | 51.05 | 52.25 | 40.44 | 41.13 | 43.32 |
| Sand | 67.85 | 66.85 | 66.07 | 65.08 | 64.88 | 65.08 | 50.16 | 51.05 | 52.37 | 39.80 | 41.32 | 43.67 |
| Loam | 67.82 | 67.00 | 65.52 | 65.76 | 65.82 | 65.08 | 50.68 | 51.48 | 52.69 | 40.00 | 42.28 | 44.12 |
| Clay | 68.01 | 66.92 | 66.23 | 65.56 | 65.56 | 65.45 | 50.48 | 51.73 | 52.61 | 40.80 | 42.29 | 43.70 |
| Peat | 68.60 | 67.22 | 66.26 | 66.37 | 66.44 | 66.08 | 50.28 | 51.77 | 53.80 | 40.00 | 42.11 | 44.68 |
| Air | 72.34 | | | 68.90 | | | 54.55 | | | 41.71 | | |



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TABLE 45. — COMPARISON BETWEEN THE MONTHLY RANGE OF TEMPERATURE OF THE AIR AND OF THE DIFFERENT TYPES OF SOIL.

| Soils. | December, 1911. | | | January, 1912. | | | February. | | | March. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Gravel | 1.31 | 0.92 | 0.64 | 0.94 | 0.89 | 0.92 | 0.42 | 0.37 | 0.41 | 0.58 | 0.53 | 0.44 |
| Sand | 1.09 | 0.75 | 0.60 | 1.10 | 0.95 | 0.72 | 0.63 | 0.48 | 0.46 | 0.57 | 0.57 | 0.51 |
| Loam | 0.66 | 0.62 | 0.60 | 0.70 | 0.50 | 0.75 | 0.46 | 0.37 | 0.42 | 0.59 | 0.57 | 0.58 |
| Clay | 0.69 | 0.72 | 0.64 | 0.70 | 0.62 | 0.58 | 0.47 | 0.44 | 0.32 | 0.43 | 0.43 | 0.84 |
| Peat | 0.60 | 0.61 | 0.60 | 0.76 | 0.45 | 0.41 | 0.43 | 0.39 | 0.36 | 0.47 | 0.46 | 0.43 |
| Air | 16.77 | | | 16.68 | | | 21.58 | | | 30.49 | | |
| Soils. | April. | | | May. | | | June. | | | July. | | |
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Gravel | 4.93 | 2.66 | 0.96 | 6.59 | 3.18 | 0.83 | 7.56 | 3.32 | 0.92 | 6.17 | 3.00 | 1.04 |
| Sand | 5.44 | 2.59 | 0.93 | 7.76 | 3.28 | 0.47 | 8.43 | 3.32 | 0.95 | 6.78 | 3.00 | 1.03 |
| Loam | 2.47 | 0.84 | 0.68 | 2.92 | 0.78 | 0.52 | 3.09 | 0.87 | 0.47 | 2.94 | 1.07 | 0.63 |
| Clay | 3.25 | 1.23 | 0.85 | 4.14 | 0.97 | 0.59 | 4.56 | 0.90 | 0.56 | 4.07 | 1.12 | 0.78 |
| Peat | 0.76 | 0.39 | 0.18 | 1.81 | 0.98 | 0.62 | 1.62 | 0.48 | 0.44 | 1.77 | 0.67 | 0.59 |
| Air | 31.12 | | | 32.48 | | | 41.06 | | | 36.98 | | |
| Soils. | August. | | | September. | | | October. | | | November. | | |
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| Gravel | 5.22 | 2.63 | 1.08 | 4.36 | 1.71 | 1.00 | 4.25 | 2.41 | 0.96 | 1.85 | 1.04 | 0.56 |
| Sand | 6.59 | 2.95 | 1.26 | 5.56 | 2.48 | 0.97 | 4.84 | 2.45 | 0.78 | 1.97 | 1.13 | 0.30 |
| Loam | 2.56 | 3.31 | 0.60 | 2.11 | 0.96 | 0.56 | 2.20 | 1.31 | 0.52 | 1.03 | 0.62 | 0.59 |
| Clay | 3.42 | 1.12 | 0.70 | 3.24 | 1.08 | 0.71 | 2.84 | 0.91 | 0.70 | 1.50 | 0.63 | 0.59 |
| Peat | 1.34 | 0.75 | 0.51 | 1.47 | 0.64 | 0.49 | 1.20 | 0.60 | 0.56 | 0.73 | 0.53 | 0.37 |
| Air | 34.18 | | | 35.45 | | | 31.57 | | | 19.91 | | |

From table 45 it is seen that during the winter months and up to March the air temperature was below that of the soil temperature of all three depths, during the remainder of the year the reverse was true. The greatest difference between the air and soil temperature occurred in January and the least in December and March. For the remaining months the difference lies between these extremes.

Table 46 shows that the greatest amplitude of the air temperature occurred in June and was followed in order by July, September, August, May, October, April, March, February, Decembar and January, while in the case of the soil the highest amplitude took place also in June with May, July, August, April, September, October, November, December, January, March, and February came in order. It is noticed that the order in both cases was not exactly the same yet almost alike. The range of the air temperature was far greater than that of the soils and is, of course, above it throughout all the months.

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## EFFECT OF ORGANIC MATTER ON THE TEMPERATURE OF SOILS.

### OBJECT AND METHOD OF EXPERIMENTATION.

Organic matter possesses two physical properties which have a remarkable influence upon the soil temperature. These are color and water holding capacity. The soils with the largest amount of organic matter will have the darkest color. Dark or black colored soils, possessing the highest absorbing capacity for heat, would tend to be much warmer than the light colored or white soils, which have less heat absorbing power. On the other hand, the soils with the greatest organic content carry also the largest amount of water, and water possessing such great specific heat and other properties, would tend to keep the temperature of these soils low. It was in order to ascertain to what extent these two physical properties of the organic matter would oppose each other, that the following experiment was undertaken. It consisted of studying the daily temperature of a sandy soil which contained organic matter in the proportions of 1.81, 2.01, 3.32, 5.47, 6.95% and 100% peat. It was prepared by excavating a trench over 3 feet deep and 3 feet wide, placed in it wooden boxes 3x3x3 feet without bottom or top and filled them with a sandy soil. The soil of the upper 21 inches was then taken from each box, added to it the proper amount of organic matter (peat), thoroughly mixed, and then placed back into the box. The percentages of organic matter shown above represent the percentage amounts found by the ignition method, after the respective proportions of peat were added. To the soil showing 1.81% organic matter no peat was added. This is, therefore, the original organic content of the soil as determined by the above method. These various amounts of organic matter imparted to the soil different shades of color, ranging from very light to very dark. The soil with the 1.81% organic matter was covered with a very thin layer of very white quartz sand, thus giving to it a very white color.

The experiment was prepared and was ready for the intended study by October, 1911, but because of an accident to the thermometers, the temperature records were not commenced till the middle of February, 1912.

The temperatures were taken by the electrical resistance thermometers already described, at two different depths, 5 and 18 inches, daily throughout the year, except on Sundays, three times a day at, 7 A. M., 12 M., and 6 P. M.

The tables to follow show the daily, monthly, seasonal, and yearly maximum, minimum and average temperatures, for all the soils at both depths. All the tables with few exceptions are accompanied by diagrams to show their salient facts graphically. On the daily temperature charts are also plotted the meteorological data in order to show more readily any influence that they might have on the soil temperature.

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## DAILY AND MONTHLY AVERAGE TEMPERATURE.

TABLE 46.—EFFECT OF ORGANIC MATTER ON THE TEMPERATURE OF SOILS. DAILY AVERAGE, MARCH, 1912.

| Date. | Peat. | | 6.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.01% Org. Matter. | | 1.61% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 31.95 | 32.2 | 32.1 | 32.15 | 32.2 | 32.35 | 32.15 | 32.45 | 32.1 | 32.2 | 31.80 | 32.05 |
| 2 | 31.66 | 32.3 | 31.9 | 32.1 | 31.93 | 32.1 | 32.03 | 32.63 | 32.03 | 32.36 | 31.5 | 31.9 |
| 4 | 31.16 | 32.3 | 32.1 | 32.1 | 23.13 | 32.1 | 32.1 | 32.3 | 31.1 | 32.2 | 30.16 | 31.7 |
| 5 | 30.4 | 32. | 31.95 | 31.95 | 30.7 | 31.85 | 31.05 | 32.0 | 29.85 | 32 1 | 29.5 | 31.55 |
| 6 | 29.43 | 32.03 | 30.4 | 31.66 | 29.66 | 31.76 | 29.73 | 31.83 | 28.93 | 31.7 | 29.16 | 31.0 |
| 7 | 29.13 | 32.06 | 30.3 | 31.9 | 29.7 | 32.66 | 29.8 | 32.66 | 28.8 | 31.5 | 28.26 | 30.73 |
| 8 | 29.3 | 32.13 | 30.36 | 31.73 | 30.06 | 32.0 | 30.23 | 32.2 | 29.93 | 31.53 | 29.0 | 30.9 |
| 9 | 29.66 | 31.93 | 30.9 | 31.96 | 30.46 | 31.76 | 30.26 | 32.06 | 29.33 | 32.0 | 29.1 | 30.76 |
| 11 | 29.96 | 32.06 | 30.6 | 32.03 | 30.26 | 31.7 | 30.23 | 32.1 | 30.06 | 31.43 | 29.16 | 31.3 |
| 12 | 30.0 | 31.9 | 31.03 | 31.83 | 30.3 | 31.56 | 30.2 | 31.83 | 29.96 | 30.90 | 29.03 | 30 73 |
| 13 | 30.33 | 31.8 | 30.76 | 31.66 | 30.46 | 31.73 | 30.66 | 31.33 | 30.3 | 31.73 | 29.46 | 30 93 |
| 14 | 29.46 | 31.2 | 29.83 | 31.0 | 29.7 | 30.96 | 29.8 | 31.23 | 29.6 | 30.8 | 28.63 | 30.3 |
| 15 | 29.5 | 31.4 | 30.4 | 31.5 | 30.1 | 31.4 | 30.1 | 31.6 | 30.2 | 31.7 | 30.1 | 31.8 |
| 16 | 30.13 | 31.1 | 30.3 | 31.43 | 30.4 | 31.23 | 30.43 | 31.5 | 30.3 | 31.3 | 29.96 | 31.03 |
| 18 | 29.9 | 31.23 | 30.93 | 31.46 | 31.1 | 31.33 | 31.1 | 31.83 | 31.3 | 31.83 | 30.53 | 31 06 |
| 19 | 30.8 | 31.33 | 31.13 | 31.43 | 31.16 | 31.3 | 31.16 | 31.66 | 31.16 | 31.76 | 30.6 | 31.13 |
| 20 | 26.3 | 27.26 | 26.53 | 27.06 | 26.96 | 27.56 | 27.16 | 27.66 | 27.1 | 27.90 | 26.63 | 27.2 |
| 21 | 28.1 | 29.96 | 29.9 | 30.43 | 29.96 | 30.63 | 30.4 | 30.73 | 30.36 | 30.63 | 29.6 | 30.26 |
| 22 | 29.73 | 29.96 | 29.86 | 30.26 | 30.13 | 30.36 | 30.13 | 30.73 | 30.56 | 30.16 | 29.86 | 30.73 |
| 23 | 28.66 | 31.0 | 30.73 | 30.6 | 31.06 | 31.33 | 31.16 | 31.56 | 31.4 | 31.76 | 30.73 | 31.43 |
| 25 | 30.3 | 31.06 | 30.76 | 31.4 | 31.4 | 31.63 | 32.15 | 31.5 | 31.16 | 31.5 | 30.9 | 31.26 |
| 26 | 30.93 | 31.36 | 31.03 | 31.5 | 31.8 | 31.6 | 31.3 | 32. | 31.93 | 31.53 | 30.95 | 31.06 |
| 27 | 30.66 | 31.7 | 31.6 | 31.73 | 31.0 | 32.06 | 31.73 | 32.03 | 31.83 | 31.93 | 31.1 | 31.66 |
| 28 | 30.93 | 31.4 | 31.63 | 31.5 | 31.9 | 31.83 | 31.32 | 32.2 | 31.5 | 31.86 | 31.03 | 31.66 |
| 29 | 31.56 | 32.06 | 31.6 | 31.73 | 31.86 | 31.6 | 31.33 | 32.03 | 31.93 | 31.7 | 31.13 | 31.4 |
| 30 | 31.5 | 31.96 | 30.6 | 31.23 | 30.56 | 31.6 | 34.23 | 31.93 | 31.56 | 31.46 | 31.33 | 31.3 |
| Monthly average | 30.06 | 31.42 | 30.72 | 31.36 | 30.65 | 31.46 | 30.84 | 31.68 | 30.55 | 31.44 | 29.97 | 31.03 |

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DAILY AVERAGE TEMPERATURE FOR MARCH - 1912.

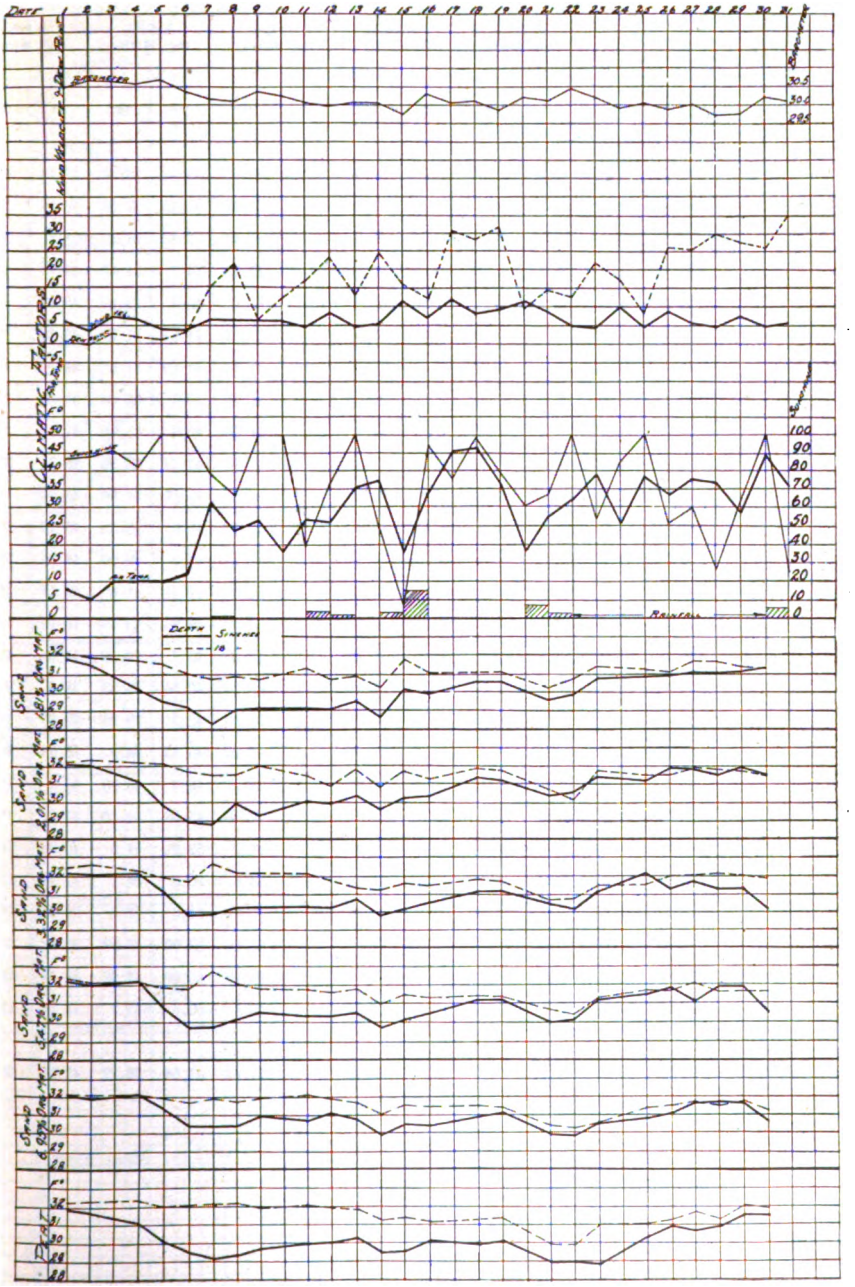


FIG. 28.

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TABLE 47.—EFFECT OF ORGANIC MATTER ON THE TEMPERATURE OF SOILS. DAILY AVERAGE APRIL, 1912.

| Date. | Peat. | | 6.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.01% Org. Matter. | | 1.81% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 31.86 | 31.8 | 32.2 | 31.56 | 32.23 | 32.06 | 32.03 | 32.03 | 32.13 | 32.23 | 31.66 | 31.7 |
| 2 | 31 56 | 31.7 | 31.53 | 31.5 | 31.56 | 31.5 | 31.56 | 31.63 | 31.33 | 31.56 | 30.8 | 31.03 |
| 3 | 31.2 | 31.53 | 31.33 | 31.3 | 31.53 | 31.5 | 31.4 | 31.43 | 31.23 | 31.36 | 31.6 | 30.86 |
| 4 | 31.13 | 31.23 | 31.0 | 31.06 | 31.53 | 31.06 | 33.76 | 31.33 | 34.7 | 31.43 | 30.73 | 30.33 |
| 5 | 31.46 | 31.8 | 33.93 | 31.8 | 36.86 | 31.8 | 40.16 | 32.0 | 40.8 | 31.63 | 40.13 | 31.16 |
| 6 | 31.26 | 31.73 | 38.7 | 31.43 | 41.56 | 31.76 | 45.1 | 31.86 | 44.63 | 31.73 | 42.26 | 31 26 |
| 7 | 31.36 | 31.56 | 33.86 | 31.36 | 35.16 | 31.56 | 35.0 | 31.7 | 35.16 | 31.6 | 34.13 | 31 06 |
| 8 | 31.43 | 31.56 | 34.5 | 31.5 | 35.83 | 31.56 | 37.26 | 31.73 | 37.4 | 31.66 | 35.36 | 31 16 |
| 9 | 31.4 | 31.76 | 39.7 | 31.63 | 41.9 | 31.6 | 44.03 | 31.96 | 43.3 | 31.76 | 42.1 | 31.7 |
| 10 | 31.23 | 31.56 | 41.03 | 31.53 | 43.46 | 31.5 | 43.30 | 31.4 | 43.23 | 32.36 | 40.7 | 33.1 |
| 11 | 32.53 | 31.53 | 42 43 | 31 53 | 45 86 | 31.53 | 48.63 | 34.93 | 47.16 | 34.56 | 45.03 | 35.96 |
| 12 | 34.2 | 31.6 | 43.03 | 31.6 | 45.96 | 32.9 | 47.76 | 38.26 | 47.0 | 38.1 | 45.23 | 38 3 |
| 13 | 34.7 | 31.43 | 42.0 | 31.4 | 45.26 | 38 2 | 46.8 | 39.33 | 46.2 | 39.06 | 44.26 | 38.96 |
| 15 | 38.96 | 31.5 | 49.96 | 40.7 | 50.76 | 42 7 | 50.66 | 41.66 | 47.1 | 41.6 | 49.13 | 41 16 |
| 16 | 38.8 | 31.93 | 47.96 | 42.56 | 49.03 | 43.7 | 49.56 | 43.6 | 48.86 | 43.16 | 46.56 | 42.7 |
| 17 | 35.96 | 31.56 | 44.3 | 42.9 | 44.6 | 43.13 | 44.26 | 43.26 | 43.7 | 42.56 | 41.8 | 41 66 |
| 18 | 35.3 | 31.86 | 40.6 | 41.83 | 40.9 | 41.73 | 40.33 | 41.36 | 40.06 | 40.23 | 38.6 | 39.5 |
| 19 | 35.03 | 31.76 | 41.63 | 40.23 | 42.4 | 40.16 | 43.1 | 40.36 | 42.3 | 39.26 | 39.96 | 38 33 |
| 20 | 37 66 | 31.6 | 41.03 | 39.46 | 44.85 | 40 46 | 47.4 | 43.46 | 45.43 | 38 9 | 45.0 | 38.76 |
| 22 | 41.4 | 31.9 | 47.9 | 44.43 | 47.83 | 44.96 | 47.1 | 45.1 | 46.9 | 45.03 | 45.5 | 44.86 |
| 23 | 36.53 | 31.9 | 45.1 | 43.2 | 45.36 | 42.93 | 46.33 | 42.96 | 45.53 | 42.16 | 43.56 | 41.36 |
| 24 | 41.6 | 31.83 | 51.0 | 43.83 | 51.83 | 44.03 | 53.1 | 44.2 | 52.2 | 44.3 | 49.86 | 44 0 |
| 25 | 39.3 | 31.6 | 48.66 | 44.46 | 49.36 | 44.53 | 51.33 | 44.8 | 50.3 | 44.7 | 47.76 | 43 4 |
| 26 | 43 43 | 31 86 | 52 5 | 45.5 | 53.2 | 46 26 | 55.16 | 46.66 | 54.8 | 46.8 | 53.33 | 46.23 |
| 27 | 41.33 | 31.86 | 52.4 | 47.2 | 50.06 | 47.5 | 53.43 | 47.86 | 53.00 | 48.03 | 50.53 | 47.33 |
| 29 | 37.43 | 31.96 | 43 4 | 44.6 | 43.4 | 44.5 | 43.16 | 44.16 | 43.06 | 43.86 | 41 66 | 42.7 |
| 30 | 37 13 | 31.66 | 48 2 | 43 33 | 49.2 | 43.33 | 51.4 | 43.4 | 50.6 | 43.2 | 47.7 | 42.2 |
| Monthly average | 35.38 | 31.68 | 41.84 | 37.53 | 43.90 | 38.12 | 44.19 | 37.41 | 43.64 | 38.27 | 42.64 | 37.62 |

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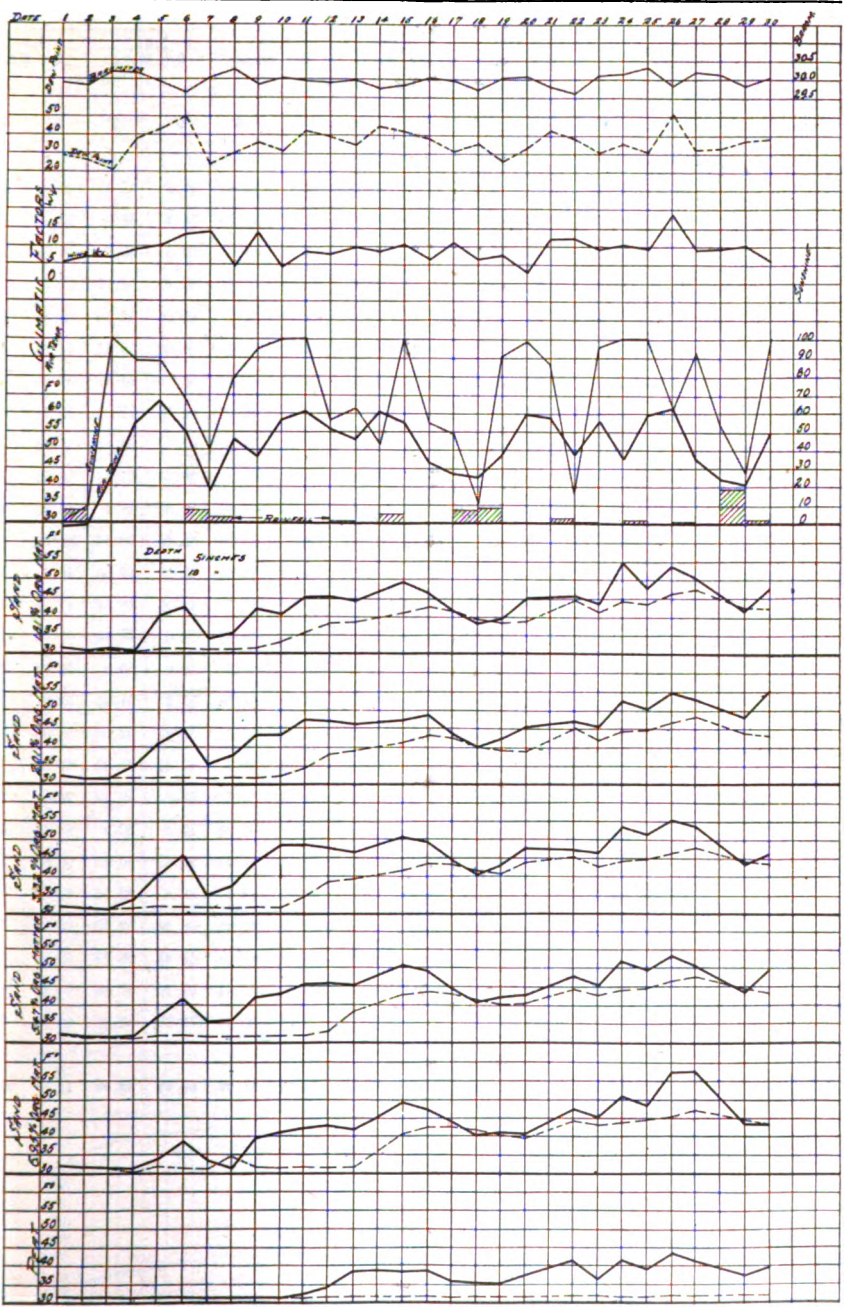


FIG. 29.

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TABLE 48.—EFFECT OF ORGANIC MATTER ON THE TEMPERATURE OF SOILS. DAILY AVERAGE, MAY, 1912.

| Date. | Peat. | | 8.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.01% Org. Matter. | | 1.81% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 39.7 | 31.73 | 47.00 | 45.4 | 47.16 | 45.56 | 47.5 | 45.56 | 47.2 | 45.43 | 45.43 | 44.6 |
| 2 | 41.13 | 31.96 | 53.13 | 45.53 | 53.93 | 45.6 | 55.6 | 45.73 | 54.4 | 46.0 | 52.3 | 45.5 |
| 3 | 44.93 | 31.96 | 57.53 | 47.83 | 58.2 | 48.3 | 59.93 | 48.7 | 59.2 | 48.9 | 56.06 | 48.5 |
| 4 | 47.26 | 32.23 | 59.9 | 49.83 | 60.13 | 50.1 | 61.46 | 50.63 | 60.4 | 50.76 | 57.3 | 50.5 |
| 6 | 51.46 | 35.86 | 62.93 | 52.23 | 63.1 | 52.26 | 64.73 | 52.7 | 63.56 | 52.86 | 60.83 | 52.46 |
| 7 | 55.23 | 39.03 | 64.86 | 54.46 | 65.03 | 54.76 | 65.86 | 55.3 | 64.66 | 55.43 | 61.26 | 54.8 |
| 8 | 55.13 | 42.96 | 59.96 | 54.56 | 60.00 | 54.36 | 60.63 | 54.46 | 59..3 | 54.43 | 57.53 | 53.53 |
| 9 | 54.7 | 49.56 | 59.53 | 54.0 | 59.76 | 53.63 | 60.3 | 53.73 | 59.13 | 53.53 | 55.9 | 52.5 |
| 10 | 55.5 | 50.9 | 62.13 | 53.73 | 62.9 | 53.8 | 63.7 | 53.9 | 62.76 | 53.63 | 58.76 | 52.76 |
| 11 | 57.16 | 51.73 | 58.8 | 55.0 | 59.0 | 55.13 | 58.86 | 55.23 | 58.43 | 55.13 | 56.63 | 54.43 |
| 13 | 49.66 | 52.7 | 47.9 | 49.63 | 50.06 | 49.03 | 50.76 | 48.96 | 50.66 | 48.4 | 48.23 | 47.33 |
| 14 | 51.4 | 51.8 | 54.53 | 50.3 | 55.43 | 49.93 | 56.3 | 50.36 | 55.46 | 50.16 | 51.96 | 48.66 |
| 15 | 49.96 | 51.83 | 48.86 | 50.76 | 48.83 | 50.33 | 48.73 | 50.63 | 48.26 | 49.63 | 46.4 | 48.36 |
| 16 | 49.63 | 51.1 | 49.36 | 49.53 | 49.46 | 49.2 | 49 26 | 49.1 | 48.96 | 48.86 | 47.56 | 48.03 |
| 17 | 49.96 | 50.56 | 53.56 | 48.83 | 54.16 | 48.73 | 55.4 | 48.93 | 55.0 | 48.73 | 52.73 | 48.03 |
| 18 | 50.6 | 50.0 | 51.26 | 50.1 | 52.1 | 49.2 | 53.1 | 49.5 | 52.9 | 50.0 | 50.75 | 47.9 |
| 20 | 52.86 | 50.6 | 55.13 | 51.6 | 55.56 | 51.53 | 55.66 | 51.56 | 55.5 | 51.26 | 53.9 | 50.53 |
| 21 | 55.5 | 51.16 | 58.9 | 52.3 | 59.36 | 52.23 | 58.96 | 52.7 | 59.43 | 52.66 | 56.06 | 52.5 |
| 22 | 59.53 | 52.63 | 65.3 | 54.5 | 67.0 | 54 73 | 69.56 | 55.5 | 69.53 | 55.83 | 66.83 | 55.83 |
| 23 | 62.93 | 52.53 | 70.93 | 57.1 | 72.36 | 57.86 | 74.06 | 58.73 | 73.2 | 59.33 | 70.0 | 59.36 |
| 24 | 65.0 | 54.9 | 69.93 | 60.1 | 69.66 | 60.43 | 69.56 | 60.86 | 70.6 | 60.9 | 68.43 | 61 03 |
| 25 | 63.63 | 56.96 | 70.26 | 59.66 | 71.0 | 59.4 | 71.73 | 59.93 | 70.83 | 60.2 | 66.66 | 59.3 |
| 27 | 66.63 | 59.43 | 69.1 | 62.43 | 69.33 | 62.3 | 68.93 | 62.6 | 69.6 | 62.56 | 67.46 | 61.63 |
| 28 | 66.26 | 59.96 | 65.7 | 61.86 | 66.4 | 61.66 | 66.46 | 61.86 | 66.36 | 62.06 | 65.26 | 61.86 |
| 29 | 63.33 | 61.13 | 59.66 | 60.66 | 58.9 | 60.06 | 58.43 | 60.26 | 58.43 | 59 93 | 56.9 | 59.13 |
| 30 | 60.83 | 60.1 | 65.16 | 57.73 | 66.53 | 57.43 | 68.6 | 57.83 | 67.16 | 57.86 | 63.83 | 56.8 |
| 31 | 63.5 | 59.33 | 69.96 | 59.76 | 70.9 | 59.76 | 72.13 | 60.2 | 70.76 | 60.03 | 66.53 | 59.1 |
| Monthly average | 54.93 | 49.84 | 59.66 | 53.68 | 60.22 | 53.69 | 60.81 | 53.90 | 60.45 | 53.69 | 57.89 | 53.15 |

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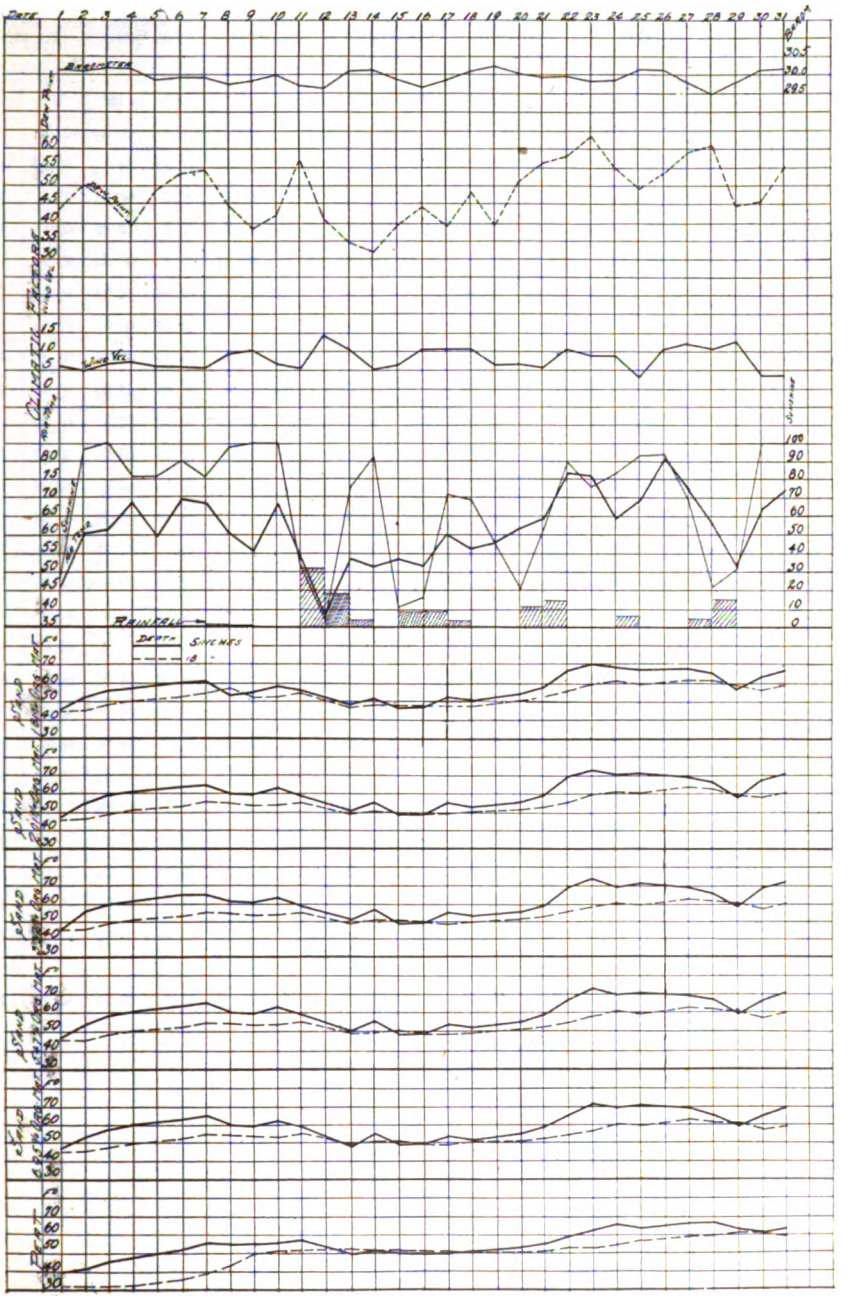


FIG. 30.

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TABLE 49.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY AVERAGE JUNE, 1912.

| Date. | Peat. | | 6.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.01% Org. Matter. | | 1.61% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 66.46 | 60.16 | 71.96 | 62.23 | 73.33 | 62.16 | 73.86 | 62.56 | 73.63 | 62.4 | 69.20 | 61.46 |
| 3 | 64.96 | 61.0 | 69.43 | 61.56 | 70.23 | 61.13 | 71.36 | 61.33 | 70.6 | 61.13 | 68.4 | 60 5 |
| 4 | 65.56 | 61.4 | 66.96 | 62.43 | 66.66 | 62.0 | 67.26 | 62.2 | 67.3 | 62.06 | 65.1 | 61.36 |
| 5 | 62.9 | 61.6 | 64.66 | 61.0 | 64.63 | 60.33 | 66.3 | 60.56 | 65.8 | 60.36 | 62.9 | 59.4 |
| 6 | 64.9 | 61.23 | 69.66 | 61.76 | 69.76 | 61.33 | 70.66 | 62.1 | 69.63 | 61.93 | 66.66 | 61.16 |
| 7 | 63.63 | 61.3 | 66.73 | 61.73 | 66.9 | 61.36 | 67.1 | 61.43 | 65.46 | 60.9 | 61.96 | 59.53 |
| 8 | 62.8 | 61.26 | 65.96 | 61.5 | 66.3 | 61.16 | 66.56 | 61.03 | 65.46 | 60.36 | 61.63 | 59.0 |
| 10 | 65.36 | 61.83 | 69.73 | 62.76 | 70.13 | 62.53 | 70.23 | 62.6 | 69.06 | 62.03 | 65.53 | 60.83 |
| 11 | 64.93 | 61.3 | 69.93 | 63.16 | 70.6 | 62.8 | 70.86 | 62.83 | 70.16 | 62.4 | 67.36 | 61.3 |
| 12 | 67.30 | 61.9 | 72.23 | 64.06 | 72.26 | 64.03 | 72.3 | 64.2 | 70.93 | 64.0 | 69.23 | 63.73 |
| 13 | 66.53 | 62.4 | 70.6 | 64.26 | 70.83 | 63.53 | 70.86 | 63.83 | 70.1 | 63.6 | 67.26 | 62.86 |
| 14 | 65.96 | 63.0 | 65.2 | 64.36 | 64.83 | 63.96 | 64.06 | 63.9 | 63.46 | 63.26 | 61.93 | 62.56 |
| 15 | 66.0 | 62.76 | 69.86 | 62.66 | 70.46 | 62.55 | 71.43 | 62.83 | 70.7 | 62.76 | 68.96 | 62.5 |
| 17 | 67.46 | 63.4 | 70.93 | 64.36 | 71.16 | 64.33 | 71.83 | 64.63 | 71.03 | 64.4 | 68.53 | 63.83 |
| 18 | 65.76 | 63.26 | 67.93 | 64.03 | 68.53 | 63.8 | 68.5 | 63.83 | 67.46 | 63.4 | 64.5 | 62.36 |
| 19 | 66.13 | 63.13 | 70.40 | 64.16 | 70.56 | 63.76 | 70.9 | 63.96 | 70.16 | 63.8 | 67.23 | 62.73 |
| 20 | 65.96 | 63.06 | 69.53 | 63.86 | 69.83 | 63.76 | 70.23 | 63.93 | 69.63 | 63.66 | 66.93 | 62.8 |
| 21 | 66.6 | 63.23 | 70.26 | 64.4 | 70.36 | 64.2 | 70.23 | 64.43 | 69.33 | 64.16 | 66.36 | 63.3 |
| 22 | 66.96 | 63.43 | 71.73 | 64.73 | 72.03 | 64.63 | 72.36 | 64.73 | 71.23 | 64.36 | 68.3 | 63.43 |
| 24 | 69.33 | 64.2 | 73.46 | 66.66 | 72.33 | 66.63 | 72.2 | 66.76 | 71.5 | 66.53 | 69.36 | 65.83 |
| 25 | 69.66 | 64.93 | 74.96 | 66.8 | 75.26 | 66.66 | 75.56 | 66.9 | 75.06 | 67.16 | 76.03 | 66.33 |
| 26 | 70.86 | 65.13 | 75.5 | 67.8 | 75.4 | 67.73 | 75.6 | 68.13 | 75.06 | 67.96 | 73.13 | 67.56 |
| 27 | 70.7 | 65.83 | 74.2 | 67.83 | 74.23 | 67.7 | 74.3 | 68.06 | 73.63 | 67.76 | 72.03 | 67.43 |
| 28 | 70.96 | 65.93 | 75.1 | 67.56 | 75.0 | 67.53 | 75.06 | 67.8 | 74.0 | 66.7 | 73.93 | 67.4 |
| 29 | 71.76 | 65.53 | 75.8 | 67.63 | 76.1 | 67.63 | 69.96 | 67.9 | 75.16 | 66.63 | 77.03 | 66.6 |
| Monthly average | 84.12 | 62.68 | 70.51 | 63.76 | 70.70 | 63.89 | 70.76 | 84.10 | 70.24 | 63.66 | 67.88 | 63.62 |

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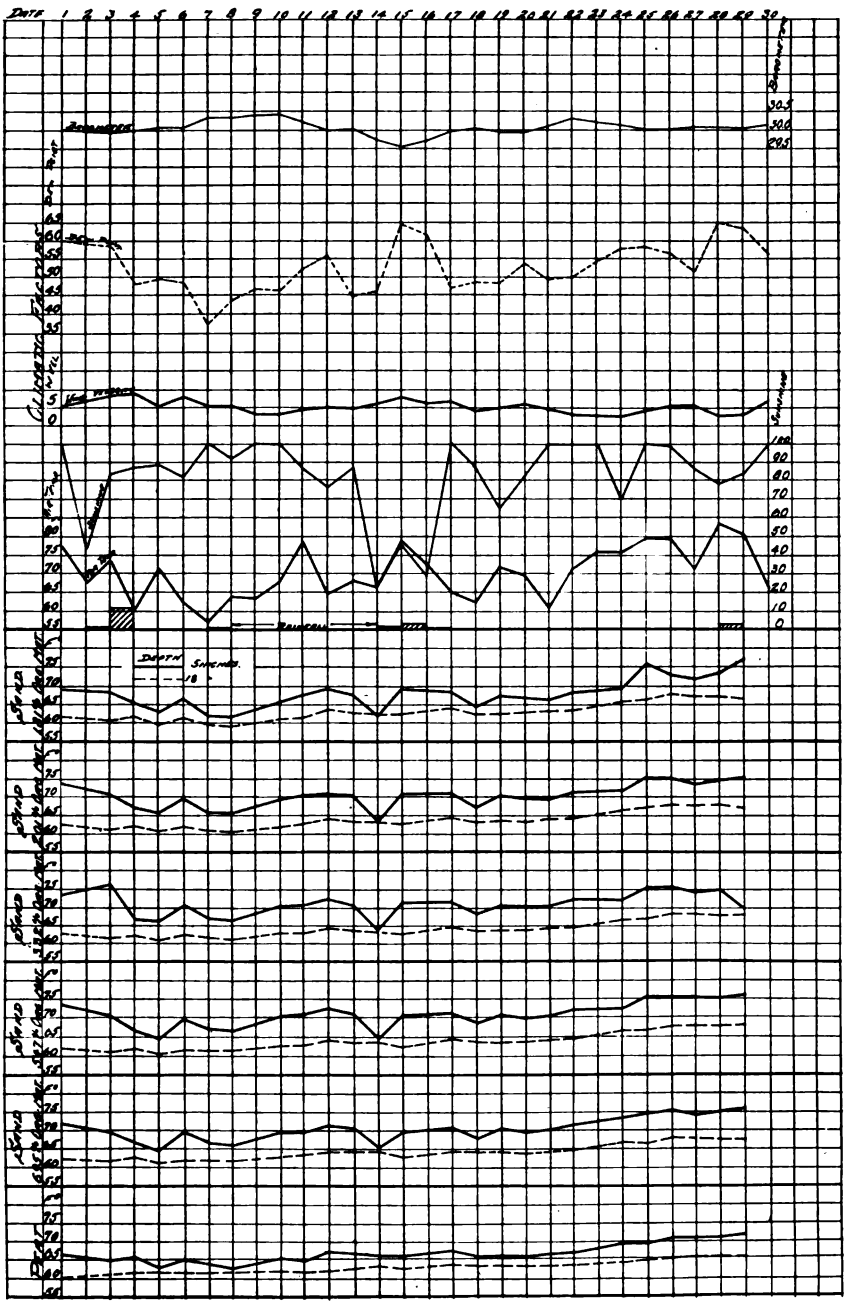


FIG. 31.

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TABLE 50.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY AVERAGE. JULY, 1912.

| Date. | Peat. | | 6.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.61% Org. Matter. | | 1.81% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 70.63 | 67.1 | 73.63 | 68.4 | 73.66 | 68.13 | 73.96 | 68 23 | 73.23 | 68.0 | 71.2 | 67.33 |
| 2 | 71.33 | 66.8 | 75.4 | 68 2 | 75.33 | 68.13 | 75.36 | 68.26 | 75.2 | 68.3 | 73.5 | 68.0 |
| 3 | 73.5 | 67.4 | 77.73 | 69.5 | 77.46 | 69.43 | 77.4 | 69.7 | 77.2 | 69.8 | 75.63 | 69.83 |
| 4 | 73.73 | 67.23 | 78.13 | 69.46 | 77.96 | 69.4 | 78.13 | 69.7 | 77.96 | 69.8 | 76.36 | 69.7 |
| 5 | 75.66 | 68.36 | 78.96 | 70.9 | 78.76 | 71.0 | 78 73 | 71.23 | 78.7 | 71 53 | 77.4 | 71.66 |
| 6 | 76.3 | 69.7 | 79.73 | 71.93 | 79.13 | 71.86 | 78.9 | 72.26 | 78.7 | 72.36 | 77.3 | 72 5 |
| 8 | 76.0 | 70.73 | 79.03 | 71.26 | 79.06 | 71.16 | 79.53 | 71.6 | 79.3 | 71.66 | 77.43 | 71.6 |
| 9 | 77.0 | 70.53 | 81.26 | 71.83 | 81.3 | 71.8 | 82.33 | 72.33 | 82.26 | 72.66 | 80.23 | 72 56 |
| 10 | 78.03 | 71.36 | 80.63 | 73.56 | 80.03 | 73 56 | 79.8 | 74.1 | 79.03 | 73.43 | 77.5 | 73.56 |
| 11 | 78.13 | 72.36 | 82.23 | 73.96 | 81.63 | 73.76 | 81.5 | 74.13 | 81.2 | 74.23 | 79.3 | 74.0 |
| 12 | 77.2 | 72.73 | 79.73 | 74.1 | 79.26 | 73.73 | 78.86 | 73.9 | 78.7 | 73.76 | 76.86 | 73.2 |
| 13 | 75.5 | 73.06 | 75.23 | 73.7 | 74.86 | 73.43 | 74.26 | 73.10 | 74.13 | 73.26 | 73.0 | 72.8 |
| 15 | 78.1 | 72.33 | 80.16 | 72.96 | 80.2 | 73.03 | 81.16 | 74.06 | 80.86 | 74.23 | 78.96 | 74.1 |
| 16 | 74.2 | 72.43 | 74.63 | 71.73 | 74.86 | 71.33 | 75.7 | 71.63 | 75.1 | 71.4 | 72.0 | 70.4 |
| 17 | 75 83 | 71.83 | 79.46 | 71.83 | 80.1 | 71.9 | 80 93 | 72.5 | 80.26 | 72.4 | 76.93 | 71.26 |
| 18 | 73.9 | 71.86 | 71.76 | 72.5 | 71.2 | 72.26 | 70.06 | 72.36 | 69.6 | 72.06 | 68.23 | 70.9 |
| 19 | 68.66 | 70.83 | 68.13 | 68.13 | 68.33 | 67.43 | 68.63 | 67.2 | 67.7 | 66.5 | 65.20 | 65.06 |
| 20 | 68.23 | 69.7 | 65.26 | 67.4 | 64.96 | 66.7 | 64.16 | 66.83 | 63.86 | 66.36 | 62.53 | 65.13 |
| 22 | 67.2 | 66.93 | 70.06 | 64.96 | 71.00 | 64.86 | 72.33 | 65.2 | 71.7 | 65.16 | 70.26 | 64 7 |
| 23 | 68.56 | 66.53 | 69.73 | 67.54 | 70.16 | 66.66 | 71.0 | 67.2 | 70.46 | 67.13 | 68.76 | 66.63 |
| 24 | 70.46 | 67.2 | 73.93 | 67.23 | 74.36 | 67.43 | 75.36 | 68.06 | 74.9 | 68.16 | 73.56 | 67 96 |
| 25 | 73.16 | 67.66 | 76.73 | 69.13 | 77.03 | 69.4 | 78.23 | 70.03 | 78.1 | 70.23 | 76.53 | 70.23 |
| 26 | 70.63 | 68.46 | 72.43 | 69.33 | 71.76 | 69.16 | 71.93 | 69.53 | 71.36 | 69.3 | 69.63 | 68.76 |
| 27 | 69.4 | 67.46 | 74.7 | 68.06 | 74.3 | 67.8 | 74.73 | 68.2 | 73.73 | 68.16 | 73.7 | 66.8 |
| 29 | 69.23 | 68.23 | 70.1 | 68.53 | 70.03 | 68.23 | 70.23 | 68.33 | 70.43 | 68.3 | 68.83 | 67.06 |
| 30 | 68.5 | 68.1 | 67.3 | 67.4 | 67.23 | 66 93 | 67.66 | 67.16 | 66.83 | 67.2 | 66.5 | 67 4 |
| 31 | 67.13 | 67.7 | 67.26 | 66.46 | 66.96 | 65.76 | 67.33 | 65.83 | 67.66 | 65.7 | 69 36 | 64 86 |
| Monthly average | 72.81 | 69.41 | 74.03 | 69.99 | 74.85 | 69.77 | 75.23 | 70.11 | 74.55 | 70.03 | 72.85 | 69.58 |

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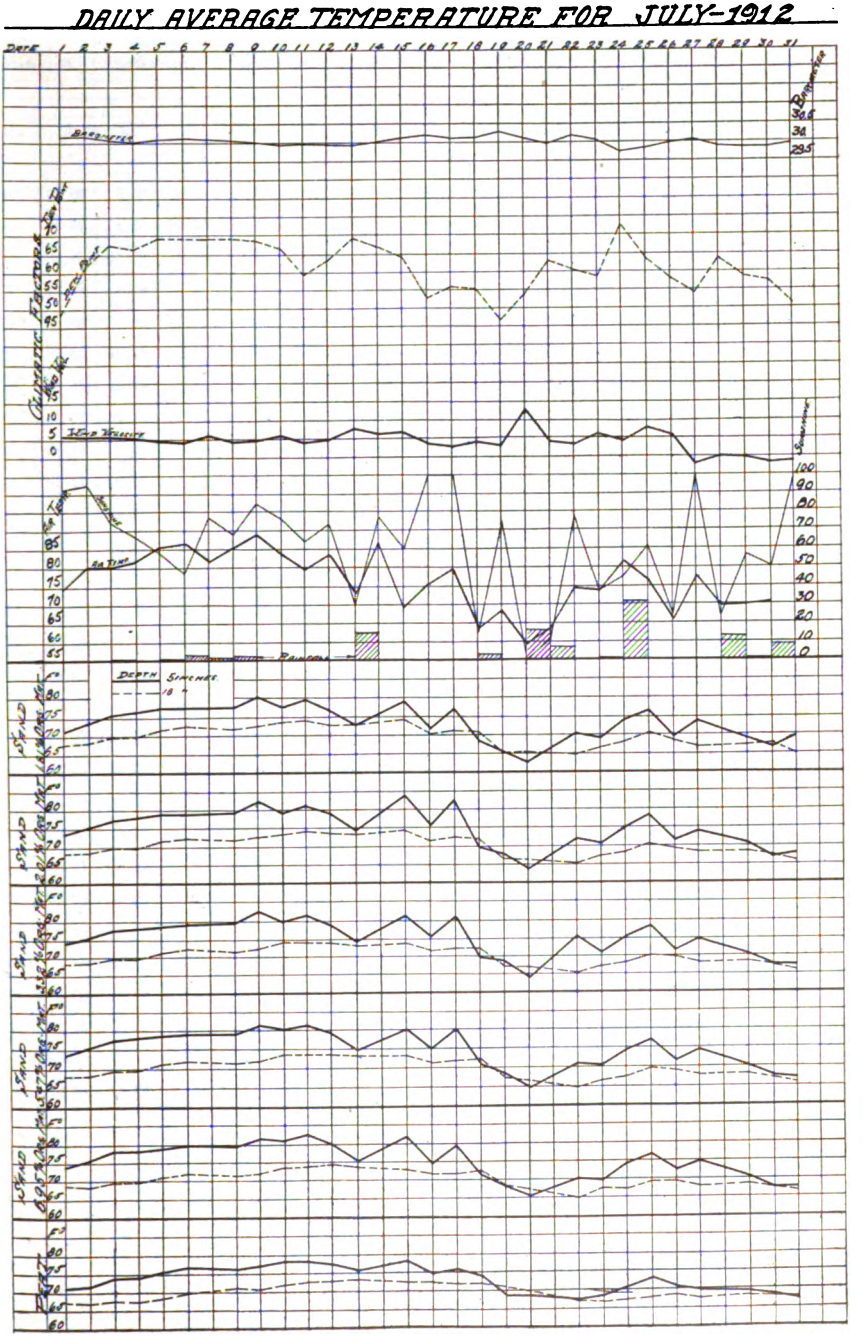


FIG. 32.

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TABLE 51.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY AVERAGE, AUGUST, 1912.

| Date. | Peat. | | 8.65% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.01% Org. Matter. | | 1.81% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 66.13 | 66.8 | 67.23 | 65.33 | 66.43 | 64.76 | 67.86 | 65.13 | 68.06 | 65.3 | 66.23 | 64.53 |
| 2 | 66.03 | 66.13 | 65.9 | 65.43 | 63.43 | 64.86 | 65.03 | 65.26 | 63.36 | 65.13 | 63.6 | 64.43 |
| 3 | 63.2 | 65.56 | 62.23 | 63.63 | 61.4 | 62.9 | 61.4 | 62.9 | 61.4 | 62.56 | 59.93 | 61.73 |
| 5 | 65.6 | 64.13 | 70.03 | 64.56 | 70.16 | 64.2 | 70.86 | 64.6 | 70.0 | 64.43 | 67.13 | 63.13 |
| 6 | 67.16 | 64.5 | 71.3 | 65.76 | 71.63 | 65.83 | 72.0 | 66.13 | 71.33 | 66.03 | 68.6 | 65.13 |
| 7 | 68.6 | 64.96 | 75.53 | 67.1 | 72.4 | 67.13 | 72.46 | 67.46 | 71.9 | 67.26 | 69.76 | 66.53 |
| 8 | 69.56 | 65.4 | 73.13 | 67.36 | 73.53 | 67.4 | 73.73 | 67.66 | 73.06 | 67.33 | 71.3 | 66.9 |
| 9 | 70 23 | 65 66 | 71.73 | 67.76 | 71.86 | 67.3 | 71.96 | 67.96 | 71.76 | 68.06 | 70.56 | 67.63 |
| 10 | 69.0 | 66.56 | 69.86 | 67.0 | 70.0 | 66.86 | 69.93 | 66 96 | 69.83 | 66.8 | 68.73 | 66.5 |
| 12 | 68 6 | 65.93 | 70.86 | 65 53 | 71.0 | 65.63 | 72 53 | 65 96 | 72 46 | 66.06 | 71.23 | 66.0 |
| 13 | 71.5 | 66 0 | 75 36 | 67.23 | 75.76 | 67.33 | 77.60 | 68.36 | 77.56 | 68.83 | 76.10 | 69.06 |
| 14 | 72.53 | 66 8 | 76 5 | 68.96 | 72.96 | 69.0 | 77 8 | 69.83 | 77.23 | 70.23 | 74.86 | 70.1 |
| 15 | 70.8 | 67.5 | 72 16 | 69.1 | 71.8 | 68.93 | 71.7 | 69.3 | 70.83 | 69.16 | 68.7 | 68.56 |
| 16 | 69.4 | 67.53 | 71.96 | 68.15 | 72.26 | 67.66 | 72.46 | 67.83 | 71.13 | 67.70 | 68.43 | 66.3 |
| 17 | 68.8 | 67.3 | 68.93 | 67.9 | 68.8 | 67.46 | 68.7 | 67.56 | 68.13 | 67.13 | 66.56 | 65.96 |
| 19 | 70.83 | 67.06 | 71.46 | 68.6 | 71.43 | 68.6 | 70.83 | 68.96 | 70.6 | 68.8 | 69.66 | 68.43 |
| 20 | 70.56 | 67.2 | 72.56 | 67.8 | 73.1 | 67.8 | 73.93 | 68.1 | 73.86 | 68.1 | 72.5 | 67.83 |
| 21 | 71.1 | 67.86 | 72.5 | 68.5 | 73.23 | 68.23 | 74.3 | 68.96 | 74.23 | 69.16 | 72.73 | 68.86 |
| 22 | 70 33 | 68.43 | 70.16 | 68.7 | 70.7 | 68.76 | 71.76 | 69.4 | 71.56 | 69.36 | 69.73 | 68.8 |
| 23 | 67.23 | 67.86 | 66.73 | 66.96 | 66.8 | 66 4 | 67.16 | 67.2 | 66.9 | 66.86 | 61.7 | 65.86 |
| 24 | 65.76 | 66 9 | 72.56 | 65.26 | 70.4 | 65.13 | 68.13 | 65 6 | 70.93 | 65.23 | 68.23 | 64.4 |
| 26 | 73.9 | 66.83 | 78.9 | 70.63 | 78.93 | 70.93 | 78.63 | 71.43 | 78.43 | 71.83 | 76.63 | 71.73 |
| 27 | 71.63 | 68.86 | 73.83 | 70.83 | 73.43 | 70.73 | 72.93 | 70.7 | 72.0 | 70.36 | 69.56 | 69.65 |
| 28 | 68.0 | 68.2 | 65 06 | 68.1 | 64.86 | 68.2 | 64.06 | 67.86 | 63.93 | 67.2 | 61.9 | 66.06 |
| 29 | 66.3 | 67.46 | 65.96 | 65.9 | 66.13 | 65.63 | 69.5 | 65 56 | 65.96 | 65.06 | 64.7 | 64.23 |
| 30 | 63.26 | 65.53 | 60.8 | 63.53 | 60.5 | 63.06 | 60.73 | 63.8 | 60.83 | 62.5 | 60.2 | 61.83 |
| 31 | 65.23 | 64.53 | 70.6 | 62.56 | 71 63 | 62.73 | 72.96 | 63.43 | 72.43 | 63.6 | 71.23 | 63.36 |
| Monthly average | 68.55 | 68.55 | 70.52 | 68.98 | 70.15 | 66.78 | 70.77 | 67.18 | 70.36 | 67.84 | 68.52 | 66.46 |

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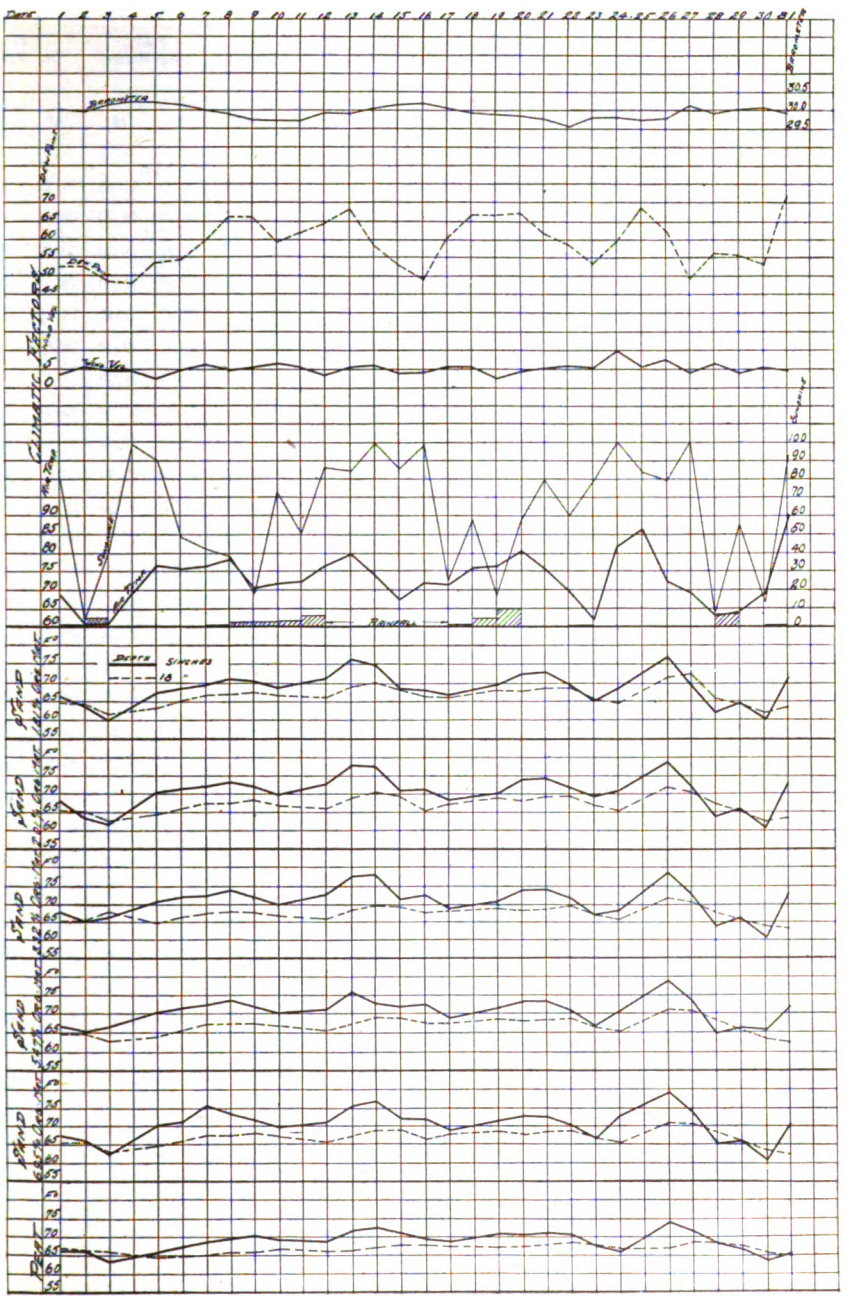


FIG. 33.

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TABLE 52.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY AVERAGE, SEPTEMBER, 1912.

| Date. | Peat. | | 6.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.61% Org. Matter. | | 1.61% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 2 | 73.17 | 66.03 | 78.60 | 69.43 | 79.43 | 69.90 | 80.03 | 70.53 | 79.37 | 70.83 | 77.23 | 70.97 |
| 3 | 73.70 | 66.90 | 77.50 | 70.20 | 77.83 | 70.53 | 77.80 | 70.87 | 76.87 | 71.00 | 75.00 | 70.80 |
| 4 | 73.70 | 68.77 | 75.70 | 71.13 | 75.87 | 71.17 | 75.67 | 71.27 | 75.07 | 71.23 | 73.43 | 70.77 |
| 5 | 73.97 | 69.33 | 77.00 | 71.00 | 77.57 | 71.17 | 77.67 | 71.57 | 77.03 | 71.43 | 74.97 | 71.10 |
| 6 | 73.87 | 69.60 | 77.37 | 71.03 | 77.97 | 71.10 | 78.40 | 71.53 | 77.87 | 71.47 | 76.80 | 71.27 |
| 7 | 74.37 | 70.00 | 77.93 | 71.70 | 78.50 | 71.83 | 78.30 | 71.83 | 77.57 | 72.00 | 76.27 | 72.07 |
| 9 | 73.67 | 69.57 | 78.43 | 71.33 | 79.30 | 71.77 | 79.53 | 72.03 | 78.60 | 71.93 | 76.43 | 71.50 |
| 10 | 74.33 | 70.27 | 78.63 | 72.57 | 79.27 | 73.10 | 79.33 | 72.90 | 78.67 | 73.07 | 76.80 | 72.53 |
| 11 | 73.00 | 70.93 | 73.70 | 72.83 | 73.53 | 72.77 | 72.47 | 73.00 | 72.77 | 72.63 | 71.80 | 72.03 |
| 12 | 68.63 | 70.47 | 66.77 | 68.97 | 67.20 | 68.67 | 67.30 | 68.60 | 67.57 | 68.40 | 66.70 | 67.33 |
| 13 | 67.17 | 69.37 | 66.83 | 67.27 | 67.60 | 67.17 | 68.57 | 67.37 | 69.07 | 67.50 | 67.23 | 66 63 |
| 14 | 67.00 | 67.90 | 66.87 | 66.50 | 67.20 | 66.50 | 67.67 | 67.07 | 67.60 | 67.03 | 66.50 | 66.37 |
| 16 | 65.80 | 66.83 | 65.27 | 65.47 | 65.63 | 65.33 | 65.30 | 65.33 | 65.10 | 65.03 | 63.97 | 64.33 |
| 17 | 63.93 | 66.40 | 61.27 | 64.83 | 61.03 | 64.53 | 60.63 | 64.47 | 60.77 | 64.17 | 59.97 | 63.40 |
| 18 | 63.73 | 65.37 | 64.23 | 63.53 | 64.53 | 63.53 | 64.70 | 63.63 | 64.53 | 63.53 | 63.67 | 62.90 |
| 19 | 61.33 | 64.90 | 58.13 | 62.97 | 58.03 | 62.83 | 58.17 | 62.60 | 58.27 | 62.27 | 57.23 | 61.00 |
| 20 | 59.90 | 63.47 | 59.97 | 61.13 | 60.07 | 60.77 | 60.77 | 60.97 | 60.37 | 60.67 | 59.27 | 57.90 |
| 21 | 61.50 | 62.87 | 62.83 | 61.57 | 63.47 | 61.63 | 64.60 | 62.10 | 64.83 | 61.90 | 63.70 | 61.53 |
| 23 | 59.60 | 62.73 | 60.00 | 61.00 | 60.70 | 60.83 | 61.17 | 61.07 | 61.00 | 60.77 | 59.50 | 59.87 |
| 24 | 59.30 | 61.43 | 59.53 | 60.47 | 60.23 | 59.93 | 60.37 | 60.17 | 60.50 | 60'03 | 59.43 | 59 27 |
| 25 | 61.43 | 61.23 | 63.90 | 60.77 | 64.90 | 60.97 | 66.03 | 61.50 | 65.43 | 61.40 | 65.70 | 61.00 |
| 26 | 61.30 | 61.70 | 59.23 | 62.03 | 58.70 | 61.93 | 59.03 | 62.33 | 59.90 | 62.40 | 58.90 | 61.80 |
| 27 | 55.03 | 62.07 | 53.57 | 58.53 | 53.73 | 58.33 | 54.33 | 58.37 | 53.80 | 57.83 | 52.27 | 56 13 |
| 28 | 54.10 | 60.06 | 51.46 | 57.30 | 51.03 | 57.03 | 50.36 | 56.96 | 50.46 | 56.93 | 49.73 | 55.40 |
| 30 | 51.53 | 57.46 | 50.36 | 54.66 | 50.36 | 54.33 | 50.56 | 53.83 | 51.03 | 53.26 | 49.96 | 53.23 |
| Monthly average | 65.80 | 65.81 | 66.61 | 65.53 | 66.96 | 65.50 | 67.15 | 65.66 | 66.96 | 65.57 | 65.69 | 64.93 |

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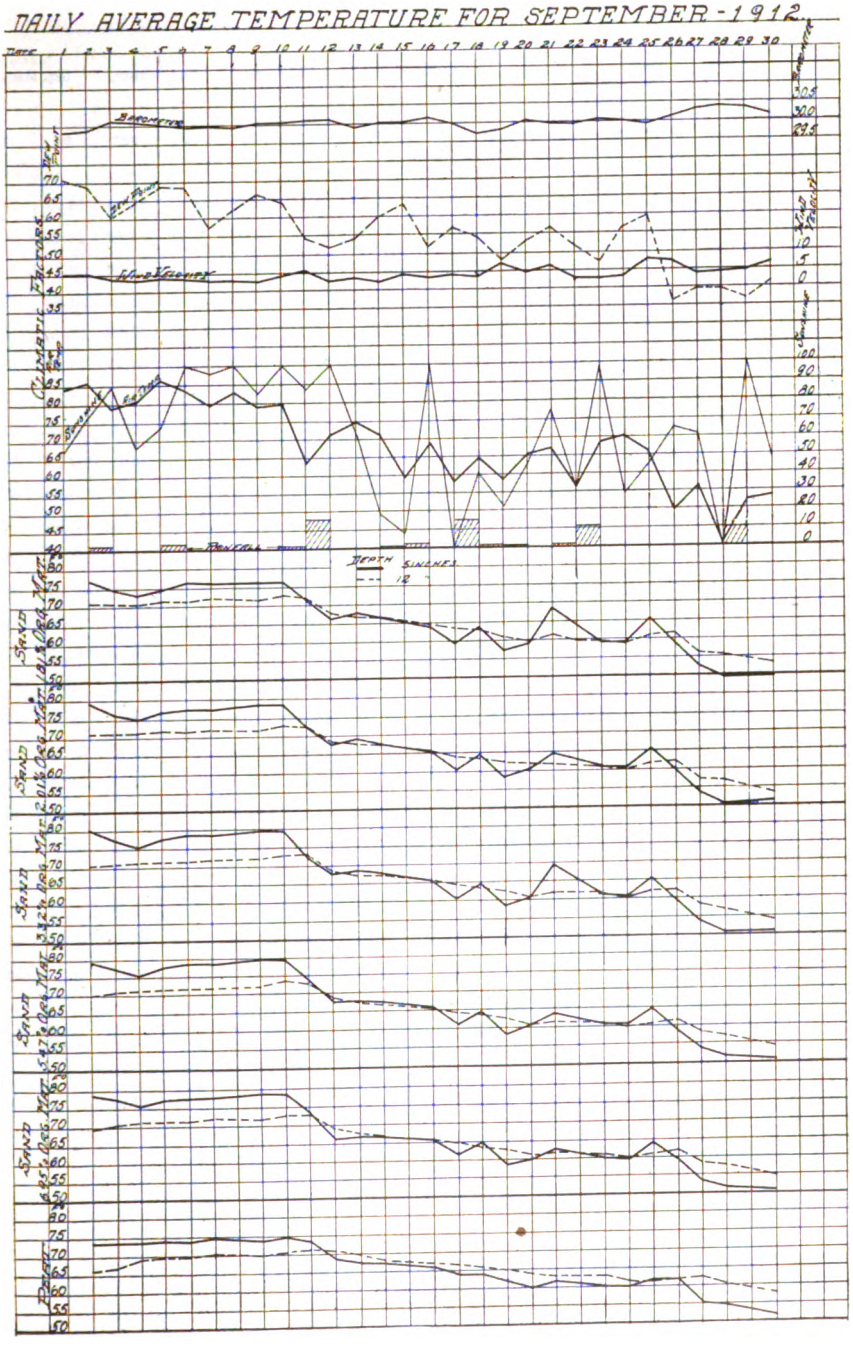


FIG. 34.



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TABLE 53.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY AVERAGE, OCTOBER, 1912.

| Date. | Peat. | | 6.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.61% Org. Matter. | | 1.81% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 51.90 | 57.26 | 53.76 | 54.40 | 54.20 | 54.23 | 54.56 | 54.30 | 54.43 | 54.00 | 53.23 | 53.03 |
| 2 | 51.76 | 56.23 | 54.16 | 54.96 | 54.76 | 54.53 | 55.33 | 54.90 | 55.36 | 54.50 | 54.03 | 53.43 |
| 3 | 52.20 | 56.23 | 52.60 | 55.50 | 52.76 | 55.20 | 53.06 | 55.30 | 53.00 | 54.96 | 52.13 | 54.13 |
| 4 | 54.9 | 55.7 | 55.95 | 55.40 | 55.95 | 55.25 | 55.95 | 55.85 | 55.60 | 55.80 | 54.65 | 55.20 |
| 5 | 54.66 | 55.86 | 57.56 | 56.23 | 58.03 | 56.20 | 56.03 | 56.13 | 58.40 | 55.90 | 57.46 | 55.83 |
| 7 | 58.26 | 56.23 | 60.03 | 58.73 | 59.66 | 58.90 | 59.50 | 59.40 | 59.60 | 59.43 | 58.66 | 59.06 |
| 8 | 52.86 | 56.60 | 51.03 | 57.03 | 50.06 | 57.16 | 49.46 | 55.63 | 49.50 | 54.96 | 48.33 | 57.10 |
| 9 | 51.83 | 55.40 | 52.36 | 54.00 | 52.76 | 53.70 | 33.00 | 53.73 | 52.56 | 53.26 | 51.53 | 52.46 |
| 10 | 54.23 | 55.60 | 54.07 | 55.17 | 54.07 | 55.07 | 54.10 | 55.07 | 53.90 | 54.73 | 53.10 | 54.27 |
| 11 | 55.47 | 55.53 | 57.00 | 55.13 | 57.10 | 55.20 | 57.30 | 55.57 | 57.07 | 55.30 | 55.90 | 55.07 |
| 12 | 56.83 | 55.63 | 55.20 | 56.77 | 54.50 | 56.57 | 53.63 | 56.63 | 53.63 | 56.43 | 53.03 | 55.90 |
| 14 | 48.55 | 54.75 | 50.40 | 51.85 | 51.75 | 51.65 | 52.35 | 51.7 | 52.35 | 51.25 | 51.85 | 50.60 |
| 15 | 48.70 | 53.90 | 48.63 | 51.87 | 49.43 | 51.10 | 48.93 | 51.50 | 48.83 | 51.00 | 47.87 | 49.97 |
| 16 | 46.57 | 52.07 | 46.83 | 50.60 | 47.23 | 50.20 | 47.40 | 50.10 | 47.23 | 49.87 | 45.70 | 48.57 |
| 17 | 47.10 | 52.17 | 49.87 | 50.53 | 51.30 | 50.53 | 51.33 | 50.70 | 50.87 | 50.30 | 49.37 | 49.13 |
| 18 | 50.47 | 51.50 | 54.47 | 52.07 | 55.20 | 52.17 | 56.60 | 52.57 | 55.67 | 52.50 | 54.67 | 52.17 |
| 19 | 50.37 | 51.50 | 48.83 | 51.60 | 49.27 | 51.97 | 48.77 | 52.27 | 48.73 | 52.07 | 48.30 | 51.50 |
| 21 | 48.87 | 52.60 | 51.11 | 51.30 | 51.70 | 51.00 | 52.10 | 51.13 | 51.57 | 50.67 | 50.73 | 49.72 |
| 22 | 52.83 | 51.77 | 53.07 | 54.93 | 55.10 | 53.30 | 54.77 | 54.00 | 54.83 | 53.47 | 54.37 | 53.37 |
| 23 | 48.17 | 51.37 | 45.10 | 50.90 | 44.13 | 50.20 | 43.10 | 50.00 | 43.40 | 49.47 | 43.20 | 48.67 |
| 24 | 45.83 | 52.43 | 44.10 | 49.83 | 43.70 | 49.13 | 43.03 | 48.73 | 43.00 | 48.03 | 42.60 | 46.77 |
| 25 | 45.40 | 51.47 | 44.70 | 48.50 | 44.77 | 47.60 | 45.13 | 47.53 | 45.33 | 47.07 | 44.60 | 46.03 |
| 26 | 45.27 | 50.77 | 46.13 | 48.40 | 46.00 | 48.10 | 46.10 | 48.03 | 46.03 | 47.73 | 45.13 | 46.83 |
| 28 | 45.63 | 49.37 | 48.27 | 48.47 | 48.10 | 48.23 | 48.77 | 48.20 | 49.10 | 47.90 | 47.53 | 46.97 |
| 29 | 47.80 | 49.57 | 50.17 | 49.83 | 50.57 | 49.73 | 51.23 | 50.07 | 51.30 | 49.93 | 50.30 | 49.40 |
| 30 | 47.10 | 49.47 | 44.43 | 49.40 | 44.10 | 49.23 | 43.37 | 49.20 | 43.50 | 48.67 | 42.73 | 48.07 |
| 31 | 43.37 | 49.50 | 39.30 | 47.50 | 39.17 | 47.00 | 38.40 | 46.77 | 38.27 | 45.67 | 37.40 | 44.03 |
| Monthly average | 50.26 | 53.37 | 50.76 | 52.63 | 50.93 | 52.34 | 50.11 | 52.41 | 50.65 | 52.04 | 49.93 | 51.37 |

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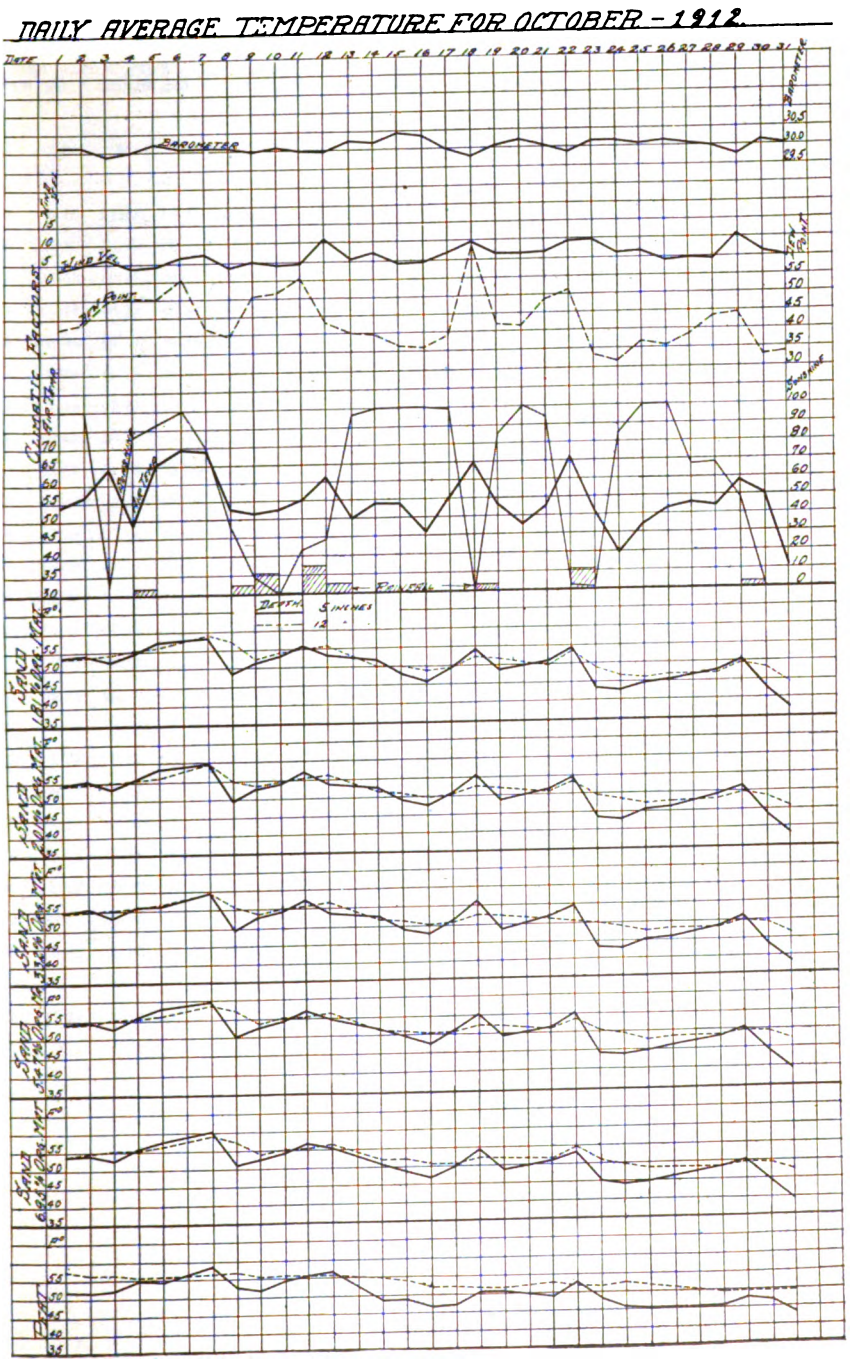


FIG. 35.

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TABLE 54.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOIL. DAILY AVERAGE, NOVEMBER, 1912.

| Date. | Peat. | | 6.95% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.01% Org. Matter. | | 1.61% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 40.16 | 48.86 | 36.43 | 45.03 | 35.83 | 44.26 | 35.03 | 43.76 | 35.10 | 43.16 | 34.60 | 41.60 |
| 2 | 38.30 | 47.36 | 35.40 | 42.86 | 34.90 | 42.43 | 34.00 | 42.10 | 33.96 | 41.23 | 33.23 | 39.60 |
| 4 | 36.90 | 44.73 | 37.90 | 42.36 | 38.00 | 42.03 | 37.90 | 41.86 | 38.26 | 41.23 | 37.56 | 39.96 |
| 5 | 40.10 | 44.23 | 43.73 | 43.70 | 44.30 | 43.76 | 45.20 | 43.90 | 44.90 | 43.60 | 44.23 | 42.96 |
| 6 | 45.86 | 44.50 | 48.80 | 46.56 | 49.20 | 46.90 | 49.03 | 47.40 | 49.16 | 47.36 | 48.60 | 47.16 |
| 7 | 45.76 | 45.43 | 45.73 | 47.46 | 45.60 | 47.46 | 44.53 | 47.70 | 44.45 | 47.40 | 43.46 | 46.97 |
| 8 | 42.66 | 46.06 | 42.20 | 45.93 | 42.16 | 45.43 | 42.03 | 45.20 | 42.06 | 44.76 | 41.10 | 43.83 |
| 9 | 42.40 | 46.26 | 41.93 | 45.50 | 41.96 | 45.36 | 41 93 | 45.20 | 41.80 | 44.90 | 40.90 | 43.96 |
| 10 | 43.53 | 45.33 | 46.96 | 45.33 | 47.36 | 45.56 | 48.46 | 45.60 | 48.13 | 45.40 | 47.36 | 44.53 |
| 12 | 48.63 | 45.96 | 51.30 | 48.53 | 51.56 | 48.40 | 52.20 | 48.86 | 52.00 | 48.80 | 51.30 | 48.70 |
| 13 | 50.33 | 47.66 | 50.53 | 50.23 | 50.06 | 50.53 | 49.36 | 50.83 | 49.40 | 50.70 | 48.70 | 50.46 |
| 14 | 43.90 | 48.20 | 38.76 | 47.33 | 38.10 | 46.93 | 36.96 | 46.56 | 37.06 | 46.16 | 36.23 | 44.60 |
| 15 | 40.46 | 47.90 | 36.86 | 44.50 | 36.20 | 44.03 | 35.56 | 43.70 | 35.00 | 42.80 | 33.73 | 41.40 |
| 16 | 38.20 | 46.26 | 34.80 | 42.73 | 34.10 | 42.10 | 33.20 | 41.83 | 33.00 | 40.93 | 31.63 | 39.26 |
| 17 | 37.63 | 43.50 | 37.60 | 41.96 | 37.66 | 41.80 | 36.90 | 41.60 | 37.20 | 40.90 | 36.20 | 39.63 |
| 19 | 38.13 | 43.26 | 39.46 | 42.06 | 39.73 | 41.86 | 39.86 | 42.03 | 39.76 | 41.50 | 39.06 | 40.53 |
| 20 | 38.60 | 43.06 | 39.13 | 42.36 | 39.43 | 42.26 | 40.13 | 42.10 | 39.90 | 41.63 | 38.76 | 40.66 |
| 21 | 40.00 | 42.23 | 42.23 | 42.66 | 43.06 | 42.53 | 43.76 | 42.93 | 43.86 | 42.60 | 43.26 | 42.26 |
| 22 | 39.13 | 42.90 | 37.80 | 42.93 | 37.86 | 42.76 | 38.30 | 42.43 | 38.13 | 41.70 | 37.40 | 40.26 |
| 25 | 36.87 | 42.50 | 34.73 | 40.50 | 34.57 | 40.30 | 33.73 | 39.57 | 33.67 | 38.83 | 32.70 | 37.67 |
| 26 | 36.03 | 41.73 | 34.07 | 39.43 | 34.07 | 39.27 | 33.27 | 38.97 | 33.00 | 38.20 | 32.00 | 37.17 |
| 27 | 35.70 | 41.33 | 34.20 | 39.07 | 34.10 | 39.03 | 33.80 | 38.63 | 33.17 | 38.07 | 32.20 | 36.80 |
| 29 | 36.00 | 41.65 | 34.75 | 39.50 | 34.55 | 39.15 | 34.00 | 39.05 | 33.80 | 38.40 | 32.95 | 37.30 |
| 30 | 35.47 | 40.90 | 34.17 | 38.97 | 33.77 | 38.77 | 33.17 | 38.53 | 33.07 | 38.00 | 32.03 | 36.73 |
| Monthly average | 40.45 | 44.67 | 39.97 | 43.63 | 39.92 | 43.46 | 39.68 | 43.34 | 39.58 | 42.80 | 38.72 | 41.80 |

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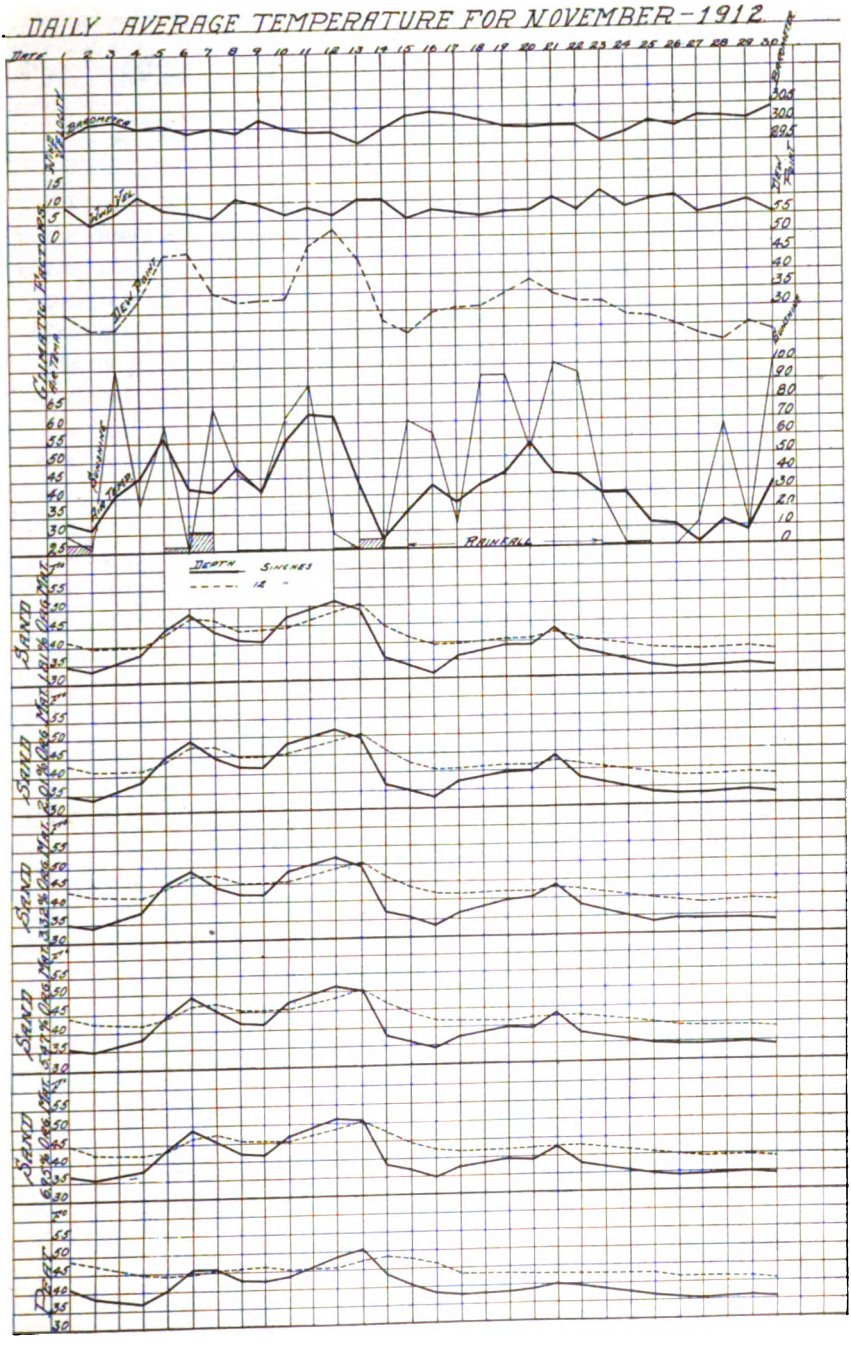


FIG. 36.

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TABLE 55.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY AVERAGE, DECEMBER, 1912.

| Date. | Peat. | | 6.66% Org. Matter. | | 5.47% Org. Matter. | | 3.32% Org. Matter. | | 2.01% Org. Matter. | | 1.81% Org. Matter. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 2 | 39.70 | 40.20 | 43.53 | 41.27 | 43.80 | 41.67 | 47.00 | 42.43 | 47.07 | 42.40 | 43 00 | 42.20 |
| 3 | 38.00 | 40.87 | 36.57 | 41.50 | 36.27 | 41.20 | 35.30 | 40.90 | 35.23 | 40.20 | 34.23 | 38.97 |
| 4 | 36.93 | 40.63 | 38.40 | 40.00 | 38.53 | 39.83 | 38.40 | 39.90 | 38.30 | 39.60 | 37.47 | 38 77 |
| 5 | 37.13 | 40.47 | 38.83 | 40.07 | 39.37 | 40.00 | 39.80 | 39.93 | 39.63 | 39.47 | 38.70 | 38 57 |
| 6 | 40.80 | 40.97 | 40.03 | 42.27 | 39.53 | 42.47 | 38.37 | 42.70 | 38.27 | 42.50 | 37.53 | 41 87 |
| 7 | 37.23 | 41.13 | 35.13 | 40.40 | 34.60 | 40.07 | 33.60 | 39.77 | 33.53 | 39.10 | 32.60 | 37 90 |
| 9 | 34.87 | 40.43 | 33.10 | 38.37 | 32.70 | 38.10 | 31.47 | 37.83 | 31.20 | 37.07 | 30.00 | 35 70 |
| 10 | 34.13 | 39.63 | 32.43 | 37.50 | 31.90 | 37.17 | 31.33 | 37.03 | 31.13 | 36.33 | 30.27 | 35.10 |
| 11 | 33.87 | 39.20 | 32.53 | 37.37 | 32.10 | 37.03 | 31.27 | 37.00 | 31.17 | 36.23 | 30 20 | 35 07 |
| 12 | 33.37 | 38.63 | 30.97 | 36.87 | 29.17 | 36.43 | 27.00 | 36.23 | 26.53 | 35.37 | 25.00 | 33 90 |
| 13 | 32.70 | 38.03 | 30.10 | 36.03 | 29.37 | 35.63 | 28.47 | 35.30 | 28.50 | 34.53 | 27.37 | 33 17 |
| 14 | 32.37 | 37.40 | 30.13 | 35.57 | 29.50 | 35.30 | 28 83 | 34.93 | 28.83 | 34.30 | 27.87 | 32.77 |
| 16 | 32 10 | 36.73 | 31 33 | 35.10 | 31.40 | 34.90 | 31.37 | 34.93 | 31.23 | 34.33 | 30 80 | 33.17 |
| 17 | 32.37 | 36.83 | 31.57 | 35.40 | 31.77 | 35.10 | 31.87 | 35.20 | 32.23 | 34.90 | 32.50 | 33 87 |
| 18 | 33.03 | 37.33 | 32.30 | 36.10 | 32 50 | 35.83 | 32.50 | 35.93 | 33.23 | 35.77 | 32.47 | 34.97 |
| 19 | 33.10 | 37.20 | 32 33 | 36.07 | 32.57 | 36 00 | 32.97 | 36.27 | 32.97 | 35.87 | 32.00 | 35.00 |
| 20 | 33.00 | 37.10 | 32.27 | 35.93 | 32 40 | 35.80 | 32.70 | 36.03 | 32.53 | 35.57 | 31.37 | 34 67 |
| 21 | 33.07 | 37.00 | 32.57 | 35.97 | 32.80 | 36.00 | 32.80 | 36.23 | 32.73 | 35.77 | 31.60 | 34.70 |
| 23 | 32.40 | 36 33 | 31.80 | 35.43 | 31.50 | 35.37 | 31 27 | 35.43 | 30 63 | 35.00 | 29.53 | 33.67 |
| 24 | 32.00 | 35.93 | 31.23 | 35.07 | 31.23 | 34.97 | 31.10 | 34.93 | 30.87 | 34.43 | 29.97 | 33.20 |
| 26 | 32.43 | 36.30 | 31.37 | 35.33 | 31.13 | 35.20 | 30 87 | 35.17 | 30.53 | 34.83 | 29.33 | 33 47 |
| 27 | 32.80 | 36 63 | 32.23 | 35.83 | 32.37 | 35.67 | 32.23 | 35.73 | 32.17 | 35.17 | 31.23 | 34.20 |
| 28 | 32.50 | 36.20 | 31.35 | 35.45 | 30.85 | 35.35 | 30.50 | 35.35 | 29.65 | 34.55 | 28.30 | 33.55 |
| 30 | 32.80 | 36.23 | 31.93 | 35.43 | 32.17 | 35.27 | 32 20 | 35.20 | 32.03 | 34.83 | 31.20 | 33 67 |
| 31 | 31.90 | 35.80 | 31.60 | 34.83 | 31.73 | 34.70 | 31.60 | 34.77 | 31.53 | 34.40 | 30.83 | 33.27 |
| **Monthly average** | **34.18** | **38.13** | **33.43** | **37.17** | **33.25** | **37.00** | **32.99** | **37.00** | **32.87** | **36.50** | **31.81** | **35.42** |

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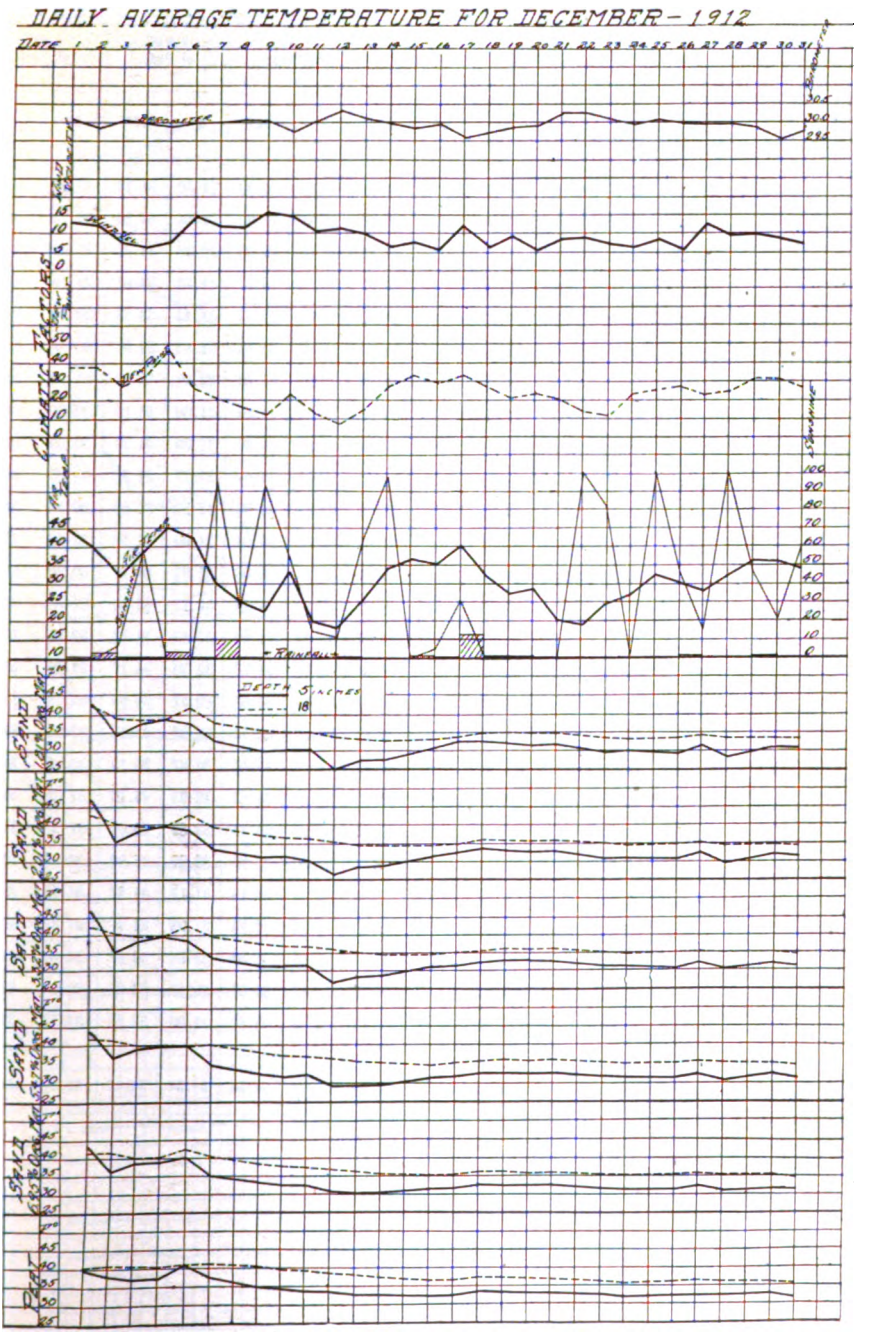


FIG. 37.

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TABLE 56.—EFFECT OF ORGANIC MATTER ON SOIL TEMPERATURE. DAILY AVERAGE, JANUARY, 1913.

| Date. | Peat. | | 6.95% of Peat. | | 5.47% of Peat. | | 3.32% of Peat. | | 2.01% of Peat. | | 1.61% of Peat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 31.77 | 35.63 | 31.50 | 34.77 | 31.60 | 34.70 | 31.43 | 34.80 | 31.30 | 34.13 | 30.57 | 33.20 |
| 2 | 31.80 | 35.53 | 31.43 | 34.80 | 31.70 | 34.80 | 31.40 | 34.80 | 31.47 | 34.20 | 30.73 | 33.27 |
| 3 | 32.33 | 35.90 | 31.97 | 35.20 | 32.13 | 35.17 | 32.10 | 35.23 | 32.00 | 34.77 | 31.03 | 33.77 |
| 4 | 32.37 | 35.90 | 32.03 | 35.10 | 31.97 | 35.07 | 31.90 | 35.17 | 31.73 | 34.83 | 31.10 | 33.80 |
| 6 | 31.70 | 35.67 | 31.47 | 34.77 | 31.47 | 34.57 | 31.53 | 34.53 | 31.43 | 33.73 | 30.60 | 32.87 |
| 7 | 32.67 | 36.33 | 32.07 | 35.37 | 32.00 | 35.37 | 31.80 | 35.33 | 31.83 | 34.90 | 30.80 | 33.90 |
| 8 | 32.80 | 36.40 | 32.60 | 35 70 | 32.30 | 35.30 | 32.30 | 35.30 | 32.10 | 34.90 | 31.10 | 34.00 |
| 9 | 31.85 | 35.30 | 31.35 | 34.55 | 31.15 | 34.50 | 31.05 | 34.60 | 31.00 | 34.10 | 29.90 | 33.15 |
| 10 | 32.17 | 35.83 | 31.70 | 34.97 | 31.47 | 34.83 | 31.33 | 34.80 | 31.30 | 34.30 | 30.30 | 33.40 |
| 11 | 32.07 | 35.67 | 31.93 | 34.80 | 32.03 | 34.60 | 32.03 | 34.63 | 31.77 | 34.23 | 31.07 | 33.23 |
| 13 | 32.40 | 35.80 | 32.40 | 35.00 | 32.37 | 35.03 | 32.43 | 34.90 | 32.30 | 34.80 | 29.50 | 33.73 |
| 14 | 32.23 | 35.83 | 32.37 | 35.00 | 32.07 | 34.97 | 32.20 | 35.03 | 31.90 | 34.60 | 30.17 | 33 37 |
| 15 | 32.17 | 35.80 | 32.47 | 35.03 | 32.10 | 35.00 | 32 23 | 35.03 | 31.93 | 34.57 | 30.80 | 33 43 |
| 16 | 32.27 | 35.77 | 32.33 | 35.13 | 32.33 | 35.00 | 32.23 | 34.83 | 32.17 | 33.90 | 31.57 | 33 33 |
| 17 | 32.23 | 35.73 | 32.30 | 35.27 | 32.37 | 34.87 | 32.30 | 34.80 | 32.43 | 34.23 | 32.23 | 33 53 |
| 18 | 32.17 | 35.67 | 32.37 | 35.10 | 32.43 | 34.77 | 32.33 | 34.77 | 32.30 | 34.17 | 31.90 | 33.80 |
| 20 | 32.70 | 35.90 | 32.73 | 35.47 | 32.70 | 35.10 | 32.63 | 35.07 | 32.57 | 34.93 | 32 23 | 34.17 |
| 21 | 32.73 | 36.10 | 32.93 | 35.50 | 32.93 | 35.43 | 38.13 | 35.53 | 32.93 | 35.13 | 32.43 | 34.63 |
| 22 | 32.70 | 35.83 | 32.93 | 35.20 | 32.87 | 35.33 | 33.17 | 35.57 | 32.87 | 35.10 | 32 00 | 34.27 |
| 23 | 32.83 | 35.90 | 32.90 | 35.27 | 32.90 | 35.37 | 33.10 | 35.63 | 32.93 | 35.10 | 31.97 | 34.23 |
| 24 | 32.63 | 35.67 | 32.87 | 35.30 | 33 07 | 35.33 | 33.03 | 35.47 | 32.83 | 35.07 | 31.97 | 34 27 |
| 25 | 32.53 | 35.70 | 32.83 | 35.07 | 33.10 | 35.30 | 32.90 | 35.30 | 32.27 | 35.00 | 30.87 | 33.93 |
| 27 | 32.43 | 35.47 | 32.77 | 35.00 | 32.97 | 35.13 | 32.10 | 35.13 | 31.17 | 34.87 | 30.40 | 33.93 |
| 28 | 31.90 | 35.37 | 30.93 | 35.00 | 31.40 | 35.00 | 28.30 | 34.93 | 27.93 | 34.37 | 27.37 | 33.40 |
| 29 | 30.57 | 35.33 | 28.17 | 34.87 | 28.60 | 34.73 | 25.90 | 34.50 | 25.07 | 33.87 | 24.60 | 32.93 |
| 30 | 31.10 | 35.07 | 30.50 | 34.10 | 30.67 | 34.17 | 30.17 | 33.97 | 30.13 | 33.27 | 29.90 | 32.57 |
| 31 | 31.90 | 35.03 | 31.80 | 34.20 | 31.40 | 34.13 | 32.13 | 33.87 | 31.93 | 33.40 | 31.17 | 32.47 |
| Monthly average | 32.18 | 35.71 | 31.99 | 35.02 | 32.00 | 34.95 | 31.75 | 34.95 | 31.54 | 34.46 | 30.68 | 33.58 |

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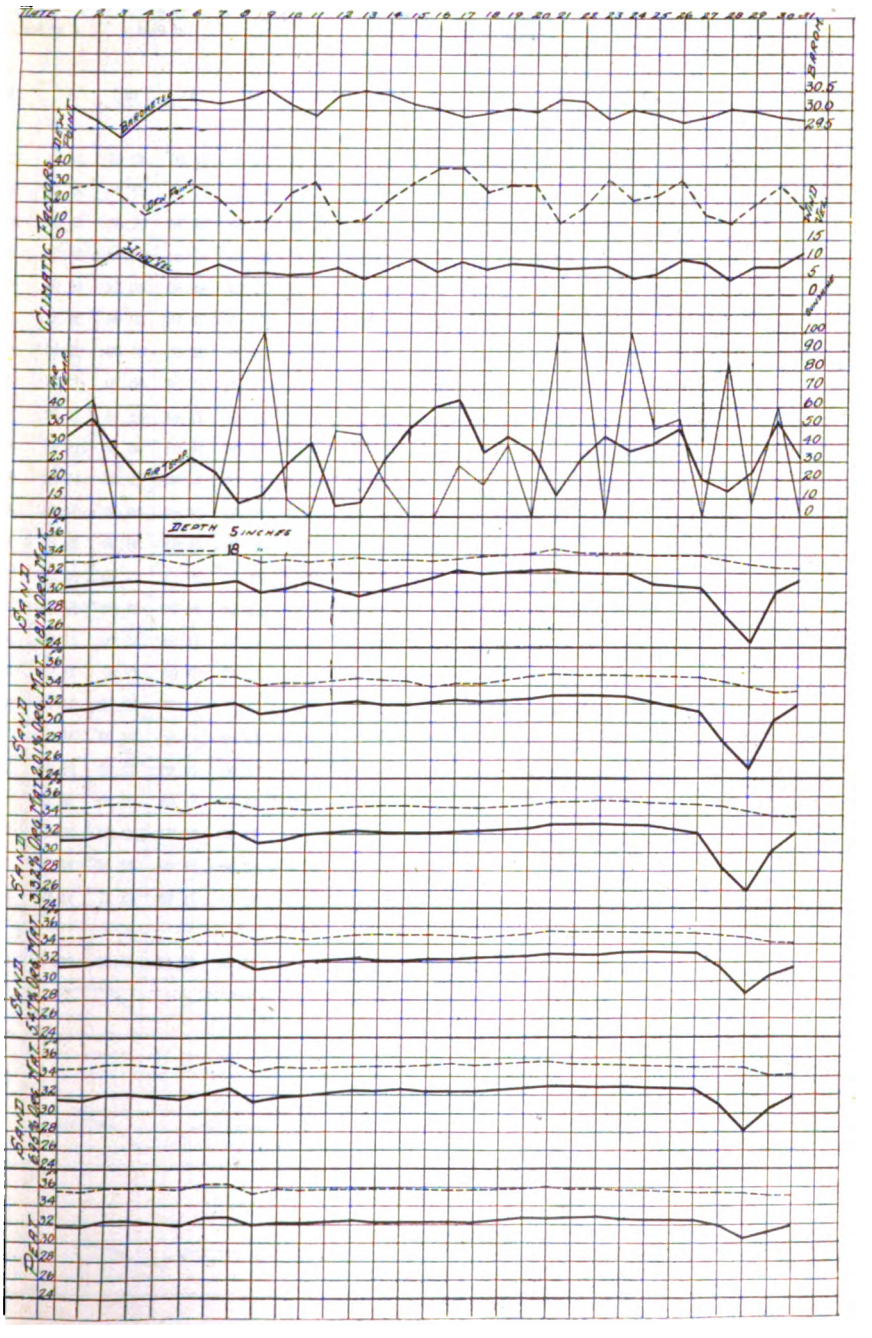
DAILY AVERAGE TEMPERATURE FOR JANUARY- 1913
DATE
CLIMATIC FACTORS
BAROMETER
AIR TEMP.
WIND VEL.
RAIN FALL
SOIL TEMP.
DEPTH 5 INCHES
18 "
STAND
BARE
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FIG. 38.

TABLE 57.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY AVERAGE, FEBRUARY, 1913.

| Date. | Peat. | | 8.05% of Peat. | | 5.47% of Peat. | | 3.32% of Peat. | | 2.01% of Peat. | | 1.61% of Peat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5 | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | 28.60 | 35.10 | 24.93 | 34.30 | 24.73 | 34.27 | 23.40 | 34.10 | 24.60 | 33.63 | 24.53 | 32.87 |
| 3 | 28.93 | 34.80 | 27.70 | 33.56 | 28.06 | 33.23 | 27.70 | 33.20 | 27.33 | 32.36 | 26.36 | 31.30 |
| 4 | 27.56 | 34.93 | 25.00 | 33.63 | 24.96 | 33.53 | 23.93 | 33.20 | 23.76 | 32.30 | 23.06 | 30.96 |
| 5 | 23.86 | 34.53 | 19.60 | 33.10 | 18.86 | 32.70 | 17.46 | 32.33 | 17.36 | 30.93 | 16.73 | 28.53 |
| 6 | 22.50 | 34.30 | 19.20 | 33.13 | 18.56 | 32.23 | 17.46 | 31.20 | 16.80 | 30.33 | 16.26 | 27.70 |
| 7 | 26.33 | 34.16 | 24.16 | 33.76 | 23.06 | 31.86 | 22.20 | 31.40 | 22.10 | 30.96 | 21.53 | 29.03 |
| 8 | 27.23 | 33.73 | 27.10 | 32.33 | 26.70 | 31 23 | 25.70 | 31.20 | 25.66 | 31.03 | 25.10 | 29.76 |
| 10 | 25.50 | 33.53 | 24.56 | 31.56 | 24.16 | 30.70 | 23.56 | 31.16 | 23.36 | 30.70 | 22.73 | 29.10 |
| 11 | 29.20 | 32.90 | 28.56 | 31.23 | 28.13 | 31.13 | 27.23 | 31.43 | 27.43 | 31.13 | 26.50 | 30.53 |
| 12 | 23.36 | 33.33 | 19.40 | 31.33 | 20.06 | 30.43 | 18.46 | 31.06 | 18.60 | 30.56 | 18.43 | 29.73 |
| 13 | 22.03 | 33 03 | 18.76 | 30.23 | 19.80 | 28.80 | 18.83 | 29.76 | 18.43 | 29.36 | 17.86 | 27.36 |
| 14 | 28.56 | 32.53 | 24.26 | 29.16 | 24.86 | 28.63 | 24.96 | 29.53 | 24.60 | 29.30 | 24.20 | 28 06 |
| 15 | 29.10 | 32.17 | 29.73 | 30.43 | 29.43 | 30.17 | 29.83 | 30.70 | 28.83 | 30.30 | 28.37 | 29 60 |
| 17 | 29.90 | 32.37 | 29.60 | 31.03 | 29.57 | 31.17 | 29.43 | 31.57 | 29.13 | 31.40 | 28.30 | 30 67 |
| 18 | 28.50 | 32.30 | 27.97 | 30.70 | 28.03 | 30.90 | 28.73 | 31.23 | 28.00 | 31.03 | 27.47 | 29 90 |
| 19 | 31.07 | 32.33 | 31.50 | 31.33 | 31.97 | 31.67 | 31.97 | 32.13 | 31.87 | 32.00 | 31.00 | 31 73 |
| 20 | 31.50 | 32.40 | 32.07 | 31.70 | 32.80 | 31 97 | 33.63 | 32.13 | 33.03 | 32.07 | 31.93 | 31 80 |
| 21 | 32.13 | 33.03 | 32.60 | 32.47 | 32.90 | 32 60 | 32.73 | 33.07 | 32.57 | 32.77 | 31.73 | 32 43 |
| 22 | 31.97 | 32.73 | 32.20 | 32.10 | 32.47 | 32 30 | 32.27 | 32.80 | 32.20 | 32.50 | 31.53 | 32.07 |
| 24 | 32 35 | 32.95 | 32.35 | 32.40 | 32.65 | 32.65 | 32.50 | 32.90 | 32.25 | 32.65 | 31.40 | 32.25 |
| 25 | 31.80 | 32.33 | 31.87 | 31.90 | 32.07 | 32.07 | 31.90 | 32.30 | 31.63 | 32.20 | 30.37 | 31.70 |
| 26 | 31.93 | 32.80 | 32.17 | 32.20 | 32.27 | 32.50 | 32.13 | 32.67 | 31.73 | 32.33 | 30.97 | 31.93 |
| 27 | 31.97 | 32.53 | 32.10 | 32.10 | 32.20 | 32.27 | 32.07 | 32.60 | 31.90 | 32.23 | 31.10 | 31.87 |
| 28 | 32.00 | 32.67 | 32.13 | 32.17 | 32.43 | 32.47 | 32.20 | 32.63 | 31.80 | 32.37 | 31.05 | 31.97 |
| **Monthly average** | **28.66** | **33.23** | **27.48** | **31.99** | **27.53** | **31.73** | **27.10** | **31.98** | **26.88** | **31.52** | **26.10** | **30.50** |

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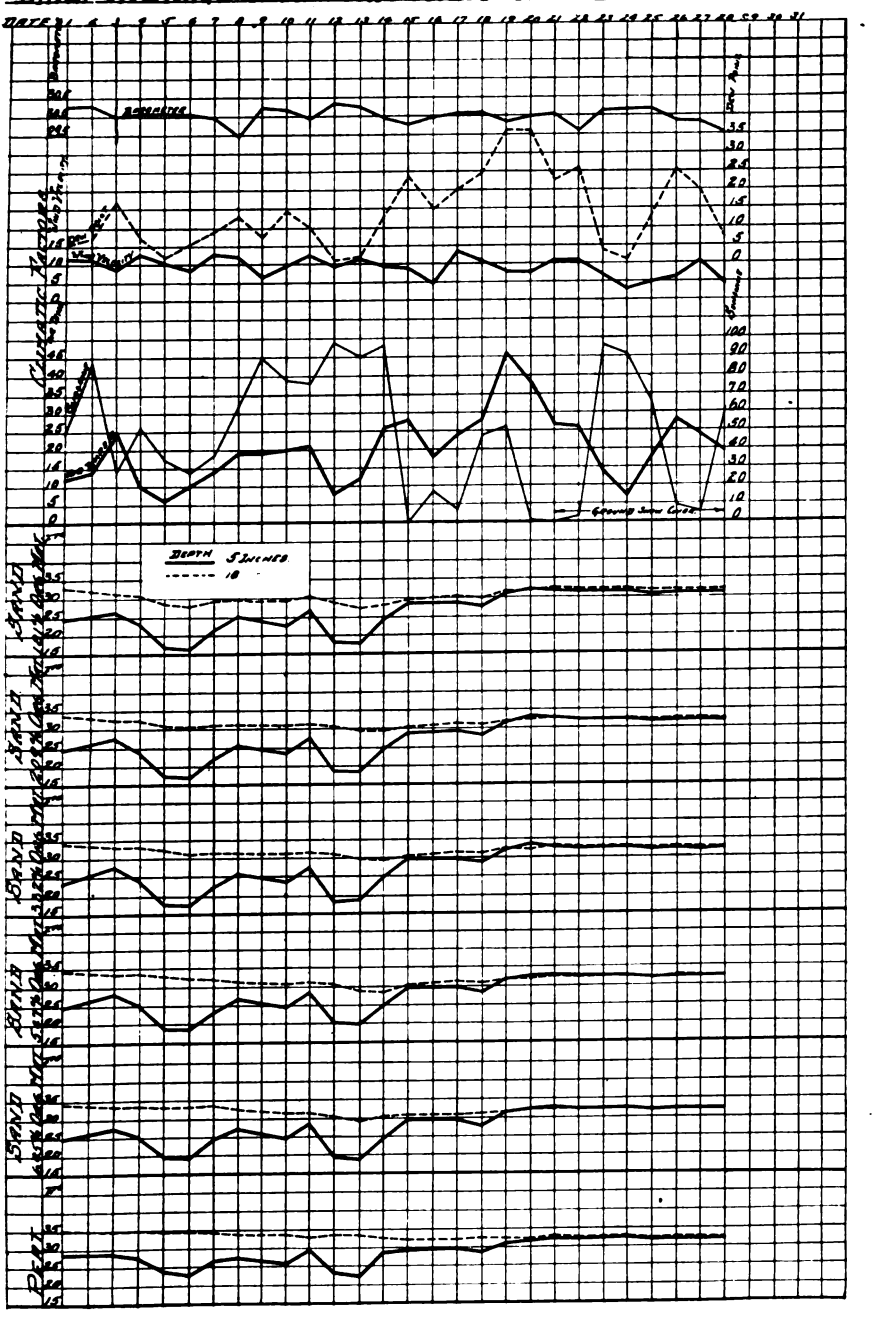


FIG. 39.

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Space does not permit full and detailed discussion of the results of this experiment, hence only the principal points will be emphasized.

All the soils at both depths remained frozen till April 4 on which day the upper 5 inches of the soil with 2.01 and 3.32% organic matter thawed, followed by the soils with 1.81, 5.4 and 6.95% organic matter the next day and by peat 7 days later. The 18 inch depth thawed in the following order: 1.81% organic matter April 10, 2.01% April 10, 3.32% April 11, 5.27% April 12, 6.95% April 15, and peat May 4. Immediately upon thawing the temperature of the soils with the lowest percentage of organic matter rose the highest followed by the other two soils in the order of their increased organic content. On the second day after the first thawing appeared, the temperature of the soil with 1.81% organic matter fell back from that of the soils with 2.01 and 3.32% organic matter but it was still ahead of the temperature of the soils with 5.42 and 6.95% organic matter. The temperature of the two latter soils attained the same magnitude as the temperature of the soils with the three lower percentages of organic matter, about April 15. At about this time the lower depths of the soils with the higher percentages of organic matter thawed, hence the logical inference would seem to be that it was probably these frozen layers below that delayed the rapid rise of the temperature of these soils. The temperature of the soils with the intermediate percentages of organic matter (2.01, 3.32, 5.47%) tended to be higher than that of the soils with 1.81 and 6.95% from the second or third day after thawing to the end of the month of April, and for all the time thereafter. The temperature of the soil with 1.81% organic matter was higher than that of the soil with 6.95% up to the middle of April and from then on it was the latter that was ahead. The temperature of the peat did not attain the same magnitude as that of the other soils until about May 11, or only a few days after the lower depth had thawed.

The temperature of all the soils at both depths continued to increase until July when the maximum was attained and then it began to decrease until freezing time. The highest temperature was attained by all soils at the upper 5 inch depth between the 9th and 11th of July. The soil with 1.81% organic matter reached its average maximum on July 9th with 80.23° F., 2.05% July 9th with 82.26°, 3.32% July 9th with 22.33°; 5.47% July 11th with 81.63°; 6.95% July 11th with 82.23°; and peat July 11th with 78.13°. At the 18 inch depth the highest average temperature was reached by the soil with 1.81% organic matter on July 11th with 74°; 2.01% on July 11th with 74.23°; 3.32% on July 11th with 73.13°; 5.47% July 11th with 73.76°; 6.95% July 12th with 74.1°; and peat on July 12th with 72.72°.

From this period on the temperature of all the soils at both depths decreased somewhat irregularly but gradually until the freezing period and then until the minimum was attained. The first freezing occurred about the first part of December, when the soils with the different amounts of organic matter froze about the same time with small variations. The soils with 1.81, 2.01, and 3.33% organic matter froze at the upper 5 inch depth on December 9th, with 5.47% on December 10th, with 6.95% on December 12th, and peat about December 13th. The 18 inch depth of the different soils froze at the following dates: 1.81% organic

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matter Feb. 3rd; 2.01% February 5th; 3.32% February 6th; 5.47% February 7th; 6.95% February 10th; and peat February 15th.

The temperature of the upper 5 inch depth of all the soils fluctuated, after the freezing point was reached, as the average temperature varied, and the amount of fluctuation was greatest when the soils were not covered with snow. The lowest average temperature reached by all the soils at the upper depth, was on Feb. 6th with the following results: 1.81% 16.26° F., 2.01% 16.80°, 3.32% 17.46°, 5.47% 18.56° F.. 6.95% 19.20°, peat 22.50°. After this date the temperature tended to fluctuate from the above points to 32° until the thawing period.

From the time of thawing to the end of September the soils with 2.01, 3.32, 5.47 and 6.95% organic matter showed a higher daily and monthly average temperature than the soil with 1.81% and peat. This was true at both depths. The temperature of the first three soils tended to be about the same through all the warmer months with a slight difference in favor of the soil with 3.32% organic matter. The temperature of peat ran considerably lower than that of the soil with 1.81% organic matter up to the end of June. From this time on until the freezing period the temperature of both soils ran about the same with a slight difference in favor of peat.

It will now be worth while to study the moisture content of these soils and compare this with their heat relationships and thereby see to what extent the object of this research has been answered.

The water content of these soils was determined several times during the warmer part of the year, but for the sake of brevity, only three determinations will be given, namely those taken April 3rd, when the soils commenced to thaw, July 27th, in the warmest month of the year, and November 4th, when the rapid cooling commenced. The data are represented herewith:

TABLE 50.—MOISTURE CONTENT OF SOIL WITH DIFFERENT AMOUNTS OF ORGANIC MATTER. FIVE INCH DEPTH.

| Date. | 1.81% | 2.01% | 3.32% | 5.47% | 6.95% | Peat. |
|---|---|---|---|---|---|---|
| April 3 | 16.96 | 12.92 | 21.80 | 26.90 | 32.53 | 256.5 |
| July 27 | 2.08 | 3.69 | 6.78 | 12.83 | 17.42 | 236.4 |
| November 4 | 2.46 | 5.85 | 8.63 | 14.46 | 21.8 | 247.8 |

It will be seen that the moisture content for all the soils varied considerably at the different times, but it increased very markedly in all of them, with the increase of the organic content. In the determinations of July and November the soil with 6.95% organic matter contained about 9 times as much water as the soil with only 1.81%, while the peat possessed almost 120 times as much as the latter and about 12 times as much as the former.

These facts lead to the important conclusion that color plays an important part in the warming of the soil and contradicts the common belief that its influence or effect is overbalanced or overshadowed by the greater moisture content that the colored soils tend to possess. The results above show conclusively that when the soils are colored,

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even in different degrees of shade, so that the reflection is considerably reduced, if not entirely eliminated, their temperature is about the same, irrespective of their moisture content, and that it is higher than that of the uncolored soil whose reflection is very great and whose moisture content is small.

The question might now be asked why peat did not also have a much higher temperature than the uncolored soil. It would have had if it were not for its water holding peculiarities. Peat or muck has not only a very great water holding capacity but also has the ability to retain and absorb water on the surface, which on account of its slow but continuous evaporation, tends to keep the temperature down. This fact is well illustrated in the following experiments. A piece of ground was covered with a thin layer of peat while another piece was covered with a thin layer of white sand. The temperature records taken several times throughout the summer show that both plots at the depth of 7 inches were equally warm, with a slight difference in favor of the plot covered with the white sand. In another experiment, instead of using peat, dark colored sand was employed. The results show that the temperature of the dark covered soil was from 4° to 7° F., higher than that of the white covered soil. In still another experiment, wooden boxes 12 inches square and 2 inches high were filled with white sand, black dyed sand, and peat, in the dry condition, and placed out in the sun and the temperatures were taken many times during the day for several days. The results show that the temperature of the black sand was always about 5° to 6° F., higher than that of the white sand, while the temperature of the peat was lower than that of the black sand and only about 1° or 2° F., higher than that of the white sand. The results under the investigation of the temperature of the different types of soil show also that when the peat was covered with a thin layer of a sandy soil its temperature was little higher during the warmest part of the year than that of the other soils. All these facts go to prove, therefore, that the high heat absorptive power of pure peat, on account of its black color, is considerably reduced by its other properties and consequently its temperature is below that of the other types of soil.

The color of soils differs considerably. It merges into different shades of the same color or into the various colors of the spectrum. The different colors of the spectrum such as blue, green, red, yellow, etc., are found in soils. Some of them occur very rarely. There are various causes of these colors, chief of which are the humus and the iron compounds. All these natural colors, as shown by the present investigation and by the research under absorption, play a very important part in the heat relationship of the soil.

Nothing very definite can be said as to the influence of color on the temperature of soils covered with vegetation. An experiment was commenced to ascertain an answer to this question but it was too late in the season and the results obtained cannot be absolutely relied upon. It would seem, however, that extreme shades of color, such as black and white, would impart to the soils different heat relationships and especially during the early part of plant growth, which is the most important in the life history of plants. Even when the vegetation is well advanced, if the planting has not been too thick so the sun rays

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are entirely intercepted, the color will influence the warmth of the soil.

As to the influence of the meteorological elements on the temperature of these soils, the reader can obtain a better idea by referring to the charts for each month. It will suffice to mention again that these elements are too complex in their behavior and consequently the influence of all of them is not very regular.

### DAILY AND MONTHLY RANGE OF TEMPERATURE.

In the following tables with their respective charts, is shown the highest and lowest temperature as recorded tri-urnally. What has already been said concerning them under the discussion of the temperature of the different types of soil applies to the present case equally well.

The tables contain the maximum and minimum temperature, while the charts contain the differences or amplitudes of these maxima and minima temperatures. The air temperature is also the range. All the other weather elements are the averages.

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TABLE 58.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, MARCH, 1912.

| Date—Maximum, minimum. | Peat. | | 6.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.01% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 32.0 | 32.2 | 32.2 | 32.2 | 32.4 | 32.4 | 32.3 | 32.5 | 32.2 | 32.2 | 31.9 | 32.1 |
| 1 Min | 31.9 | 32.2 | 32.0 | 32.1 | 32.0 | 32.3 | 32.0 | 32.4 | 32.0 | 32.2 | 31.7 | 32.0 |
| 2 Max | 31.9 | 32.4 | 31.9 | 32.3 | 32.0 | 32.2 | 32.1 | 32.7 | 32.1 | 32.5 | 31.6 | 32.0 |
| 2 Min | 31.5 | 32.2 | 31.9 | 32.0 | 31.9 | 32.0 | 32.0 | 32.5 | 32.0 | 32.3 | 31.4 | 31.8 |
| 4 Max | 31.4 | 32.3 | 32.2 | 32.2 | 32.3 | 32.2 | 32.3 | 32.4 | 31.6 | 32.2 | 30.3 | 31.6 |
| 4 Min | 31.0 | 32.3 | 32.0 | 31.9 | 32.0 | 32.0 | 32.0 | 32.2 | 30.5 | 32.2 | 30.0 | 31.6 |
| 5 Max | 30.6 | 32.0 | 31.5 | 32.0 | 31.2 | 31.9 | 31.2 | 32.0 | 30.3 | 32.1 | 30.0 | 31.6 |
| 5 Min | 30.0 | 32.0 | 31.2 | 31.9 | 30.2 | 31.8 | 30.9 | 32.0 | 29.4 | 32.1 | 29.0 | 31.3 |
| 6 Max | 30.0 | 32.1 | 30.9 | 31.9 | 30.0 | 32.0 | 30.4 | 32.2 | 29.6 | 32.0 | 29.3 | 31.2 |
| 6 Min | 29.1 | 32.0 | 30.0 | 31.5 | 29.0 | 31.6 | 29.4 | 31.6 | 28.6 | 31.5 | 29.0 | 30.9 |
| 7 Max | 29.5 | 32.1 | 30.6 | 32.0 | 30.0 | 32.1 | 30.2 | 32.2 | 29.0 | 31.8 | 28.9 | 31.0 |
| 7 Min | 28.8 | 32.0 | 29.6 | 31.8 | 29.5 | 32.0 | 29.5 | 32.0 | 28.5 | 31.3 | 27.9 | 30.5 |
| 8 Max | 29.3 | 32.3 | 30.5 | 32.2 | 30.2 | 32.3 | 30.4 | 32.5 | 30.0 | 32.0 | 29.0 | 31.0 |
| 8 Min | 29.3 | 31.9 | 30.2 | 31.0 | 30.0 | 31.5 | 30.0 | 32.1 | 29.9 | 31.3 | 29.0 | 30.8 |
| 9 Max | 29.7 | 32.0 | 31.0 | 32.0 | 30.5 | 31.9 | 30.3 | 32.1 | 29.5 | 32.0 | 29.4 | 30.8 |
| 9 Min | 29.6 | 31.9 | 30.8 | 31.9 | 30.4 | 31.7 | 30.2 | 32.0 | 29.0 | 32.0 | 28.9 | 30.7 |
| 11 Max | 30.0 | 32.3 | 30.9 | 32.2 | 30.5 | 32.0 | 30.7 | 32.3 | 31.0 | 32.0 | 30.0 | 32.1 |
| 11 Min | 29.9 | 31.9 | 30.4 | 31.9 | 30.1 | 31.5 | 29.9 | 32.0 | 29.6 | 31.0 | 28.5 | 30.9 |
| 12 Max | 30.1 | 31.9 | 31.2 | 31.9 | 30.3 | 31.7 | 30.3 | 31.9 | 30.2 | 31.0 | 29.2 | 30.8 |
| 12 Min | 29.9 | 31.9 | 30.9 | 31.7 | 30.3 | 31.4 | 30.1 | 31.8 | 29.7 | 30.8 | 28.9 | 30.7 |
| 13 Max | 30.6 | 32.0 | 31.2 | 31.8 | 30.8 | 32.0 | 30.9 | 31.4 | 30.8 | 31.9 | 29.9 | 31.3 |
| 13 Min | 30.0 | 31.5 | 30.2 | 31.4 | 30.2 | 31.4 | 30.4 | 31.2 | 30.0 | 31.5 | 29.2 | 30.7 |
| 14 Max | 30.0 | 31.7 | 30.2 | 31.6 | 30.2 | 31.5 | 30.3 | 31.7 | 29.9 | 31.2 | 29.0 | 30.8 |
| 14 Min | 28.5 | 30.2 | 29.2 | 29.9 | 28.8 | 30.0 | 29.1 | 30.3 | 29.0 | 30.0 | 28.0 | 29.5 |
| 16 Max | 30.4 | 31.3 | 30.5 | 32.0 | 31.0 | 31.4 | 31.0 | 31.7 | 30.9 | 31.5 | 30.5 | 31.4 |
| 16 Min | 30.0 | 30.9 | 30.2 | 31.1 | 30.0 | 31.0 | 30.0 | 31.4 | 30.0 | 31.2 | 29.6 | 30.8 |
| 18 Max | 30.3 | 31.4 | 31.0 | 31.6 | 31.2 | 31.5 | 31.0 | 31.9 | 31.4 | 31.8 | 30.7 | 31.1 |
| 18 Min | 29.2 | 31.1 | 30.8 | 31.3 | 31.0 | 31.2 | 31.0 | 31.8 | 31.2 | 31.8 | 30.4 | 31.0 |
| 19 Max | 31.1 | 31.5 | 31.3 | 31.6 | 31.4 | 31.4 | 31.4 | 31.9 | 31.3 | 31.9 | 30.9 | 31.2 |
| 19 Min | 30.5 | 31.2 | 31.0 | 31.3 | 31.0 | 31.2 | 30.9 | 31.5 | 31.0 | 31.7 | 30.4 | 31.1 |
| 20 Max | 27.9 | 28.4 | 27.4 | 28.2 | 28.1 | 28.7 | 28.2 | 28.8 | 28.1 | 28.9 | 27.8 | 28.3 |
| 20 Min | 25.0 | 26.0 | 25.0 | 25.0 | 25.2 | 26.8 | 25.5 | 26.0 | 25.8 | 26.9 | 25.1 | 25.9 |
| 21 Max | 29.0 | 30.5 | 30.0 | 30.8 | 30.4 | 31.5 | 31.2 | 31.4 | 31.1 | 31.5 | 30.3 | 30.7 |
| 21 Min | 28.0 | 29.4 | 29.8 | 30.1 | 29.5 | 30.0 | 29.8 | 30.3 | 29.9 | 30.1 | 29.2 | 30.0 |
| 22 Max | 30.5 | 30.5 | 30.3 | 30.5 | 30.6 | 30.9 | 30.6 | 31.4 | 31.1 | 31.0 | 30.4 | 31.1 |
| 22 Min | 28.9 | 29.4 | 29.1 | 30.0 | 29.6 | 29.8 | 28.0 | 30.0 | 29.7 | 29.4 | 29.0 | 30.0 |
| 23 Max | 29.1 | 31.4 | 30.9 | 30.9 | 31.2 | 31.7 | 31.4 | 31.7 | 31.4 | 32.0 | 31.9 | 31.6 |
| 23 Min | 28.0 | 30.5 | 30.4 | 30.4 | 31.0 | 31.1 | 31.0 | 31.5 | 31.3 | 31.6 | 30.5 | 31.2 |
| 25 Max | 30.8 | 31.4 | 31.0 | 31.8 | 31.7 | 31.9 | 32.0 | 31.7 | 31.5 | 31.7 | 31.0 | 31.4 |
| 25 Min | 29.8 | 30.5 | 30.5 | 30.4 | 31.0 | 31.3 | 31.5 | 31.2 | 30.6 | 31.1 | 30.8 | 31.1 |
| 26 Max | 31.0 | 31.5 | 31.3 | 31.6 | 31.9 | 31.7 | 31.5 | 32.1 | 32.1 | 31.7 | 31.1 | 31.2 |
| 26 Min | 30.9 | 31.1 | 30.8 | 31.4 | 31.7 | 31.4 | 31.0 | 31.9 | 31.8 | 31.2 | 30.8 | 30.9 |
| 27 Max | 31.2 | 31.8 | 31.7 | 31.8 | 32.1 | 32.1 | 31.8 | 32.2 | 31.9 | 32.1 | 31.2 | 31.9 |
| 27 Min | 30.3 | 31.6 | 31.5 | 31.7 | 31.8 | 32.0 | 31.6 | 31.7 | 31.7 | 31.7 | 31.0 | 31.4 |
| 28 Max | 31.2 | 31.5 | 31.9 | 31.7 | 32.0 | 31.9 | 32.0 | 32.4 | 31.6 | 32.1 | 31.1 | 31.8 |
| 28 Min | 30.6 | 31.3 | 31.3 | 31.2 | 31.8 | 31.7 | 30.6 | 31.9 | 31.3 | 31.7 | 31.0 | 31.4 |
| 29 Max | 31.9 | 32.2 | 31.8 | 31.9 | 31.9 | 31.8 | 31.5 | 32.1 | 32.1 | 32.0 | 31.5 | 31.7 |
| 29 Min | 31.3 | 32.0 | 31.4 | 31.5 | 31.8 | 31.3 | 31.0 | 32.0 | 31.7 | 31.3 | 30.7 | 31.0 |
| 30 Max | 31.8 | 32.1 | 31.0 | 32.0 | 31.3 | 31.7 | 31.5 | 32.1 | 31.7 | 31.6 | 31.9 | 31.4 |
| 30 Min | 31.3 | 31.8 | 29.8 | 30.7 | 29.2 | 31.4 | 29.7 | 31.7 | 31.4 | 31.2 | 30.9 | 31.2 |
| Monthly range | 0.72 | 0.48 | 0.57 | 0.64 | 0.66 | 0.52 | 0.79 | 0.44 | 0.67 | 0.56 | 0.66 | 0.52 |

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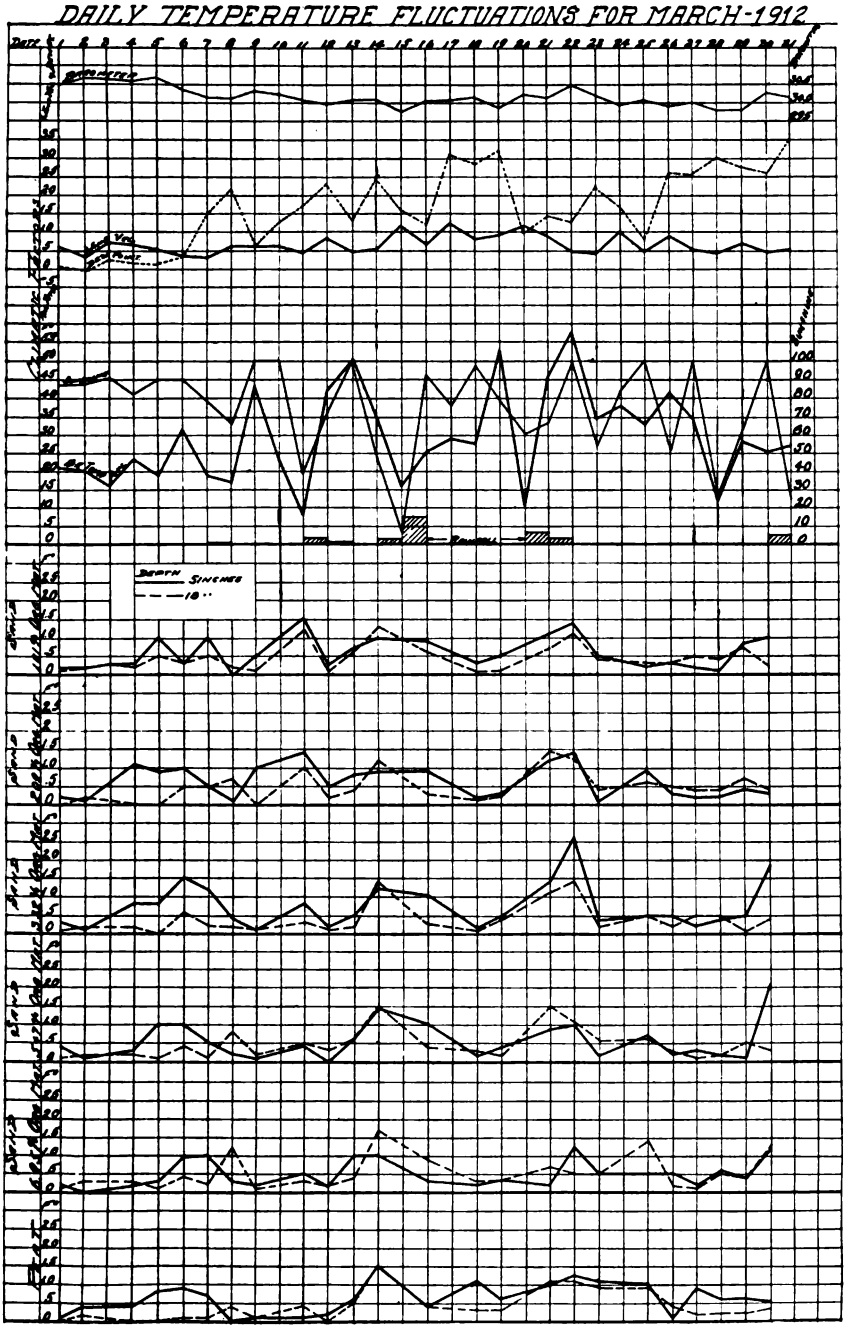


FIG. 40.



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TABLE 59.—EFFECT OF ORGANIC MATTER ON THE TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, APRIL, 1912.

| Date—Maximum, minimum. | Peat. | | 0.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.91% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 32.0 | 32.0 | 32.3 | 32.1 | 32.4 | 32.2 | 32.1 | 32.2 | 32.4 | 32.4 | 32.0 | 32.0 |
| 1 Min | 31.7 | 31.4 | 32.0 | 31.7 | 31.9 | 31.9 | 31.9 | 31.8 | 32.0 | 32.1 | 31.2 | 31.3 |
| 2 Max | 31.9 | 32.0 | 31.6 | 31.3 | 31.8 | 31.5 | 31.9 | 31.7 | 31.9 | 31.9 | 31.3 | 31.4 |
| 2 Min | 31.4 | 31.4 | 31.5 | 31.0 | 31.3 | 31.5 | 31.2 | 31.5 | 30.4 | 31.0 | 30.3 | 30.5 |
| 3 Max | 31.5 | 31.8 | 31.5 | 31.5 | 31.7 | 31.6 | 31.5 | 31.6 | 32.0 | 31.6 | 31.1 | 31.3 |
| 3 Min | 30.8 | 31.4 | 31.1 | 31.0 | 31.2 | 31.3 | 31.3 | 31.2 | 30.5 | 31.0 | 30.0 | 30.3 |
| 4 Max | 31.4 | 31.6 | 31.8 | 31.8 | 31.7 | 31.7 | 35.0 | 31.8 | 30.7 | 31.9 | 31.0 | 30.7 |
| 4 Min | 31.0 | 31.0 | 30.0 | 30.0 | 31.3 | 30.0 | 31.9 | 30.6 | 31.1 | 30.9 | 29.1 | 30.0 |
| 5 Max | 31.5 | 31.9 | 35.9 | 31.9 | 40.4 | 31.9 | 44.6 | 32.1 | 45.0 | 31.7 | 40.0 | 31.2 |
| 5 Min | 31.4 | 31.7 | 31.9 | 31.6 | 32.9 | 31.7 | 34.5 | 31.9 | 35.0 | 31.6 | 32.4 | 31.1 |
| 6 Max | 31.5 | 31.9 | 41.9 | 31.5 | 46.2 | 31.9 | 40.9 | 32.0 | 40.7 | 31.9 | 40.5 | 31.3 |
| 6 Min | 31.0 | 31.5 | 34.6 | 31.3 | 36.1 | 31.5 | 38.0 | 31.7 | 38.0 | 31.5 | 36.5 | 31.2 |
| 7 Max | 31.5 | 31.8 | 34.5 | 31.5 | 36.0 | 31.9 | 35.7 | 31.9 | 35.8 | 31.7 | 35.0 | 31.1 |
| 7 Min | 31.3 | 31.4 | 33.3 | 31.3 | 34.5 | 31.3 | 34.1 | 31.5 | 34.6 | 31.5 | 33.5 | 31.0 |
| 8 Max | 31.5 | 31.8 | 39.9 | 31.7 | 41.9 | 31.7 | 43.9 | 32.1 | 43.9 | 31.8 | 41.2 | 31.2 |
| 8 Min | 31.4 | 31.4 | 31.6 | 31.3 | 32.0 | 31.4 | 31.4 | 31.5 | 31.6 | 31.6 | 30.9 | 31.1 |
| 9 Max | 31.4 | 31.8 | 45.0 | 31.7 | 47.8 | 31.6 | 50.1 | 32.0 | 49.1 | 31.8 | 47.9 | 32.5 |
| 9 Min | 31.4 | 31.7 | 34.4 | 31.6 | 35.1 | 31.6 | 35.0 | 31.9 | 35.8 | 31.7 | 34.0 | 31.2 |
| 10 Max | 31.7 | 31.6 | 46.6 | 31.0 | 49.7 | 31.7 | 51.6 | 31.9 | 50.5 | 33.2 | 47.0 | 30.0 |
| 10 Min | 31.0 | 31.5 | 33.0 | 31.5 | 33.9 | 31.3 | 33.2 | 31.2 | 33.2 | 31.9 | 32.3 | 32.1 |
| 11 Max | 34.5 | 31.6 | 49.1 | 31.6 | 53.4 | 31.6 | 55.9 | 39.8 | 54.5 | 39.4 | 52.0 | 38.0 |
| 11 Min | 31.7 | 31.5 | 35.5 | 31.5 | 36.9 | 31.5 | 37.4 | 33.5 | 37.2 | 33.4 | 36.0 | 34.9 |
| 12 Max | 36.0 | 31.6 | 46.9 | 31.6 | 49.1 | 35.0 | 51.0 | 39.9 | 50.3 | 39.0 | 48.0 | 39.0 |
| 12 Min | 32.8 | 31.6 | 39.7 | 31.6 | 42.8 | 31.7 | 42.5 | 37.9 | 42.5 | 37.5 | 41.5 | 37.9 |
| 13 Max | 36.4 | 31.5 | 45.0 | 31.5 | 49.1 | 39.9 | 50.8 | 40.0 | 48.4 | 39.4 | 47.7 | 39.5 |
| 13 Min | 33.1 | 31.4 | 38.9 | 31.3 | 41.2 | 37.6 | 41.8 | 39.0 | 41.8 | 38.9 | 40.1 | 38.6 |
| 15 Max | 42.9 | 31.5 | 55.6 | 41.5 | 55.0 | 43.8 | 56.9 | 44.5 | 55.9 | 44.5 | 54.5 | 44.3 |
| 15 Min | 36.0 | 31.5 | 44.1 | 40.1 | 44.8 | 42.0 | 41.0 | 38.4 | 41.0 | 38.8 | 39.9 | 38.0 |
| 16 Max | 41.5 | 32.1 | 50.9 | 43.2 | 51.5 | 44.5 | 52.5 | 44.3 | 50.9 | 44.0 | 48.5 | 43.3 |
| 16 Min | 36.0 | 31.7 | 45.1 | 42.0 | 45.4 | 42.5 | 45.0 | 42.5 | 44.8 | 42.0 | 43.3 | 41.8 |
| 17 Max | 37.9 | 31.7 | 45.0 | 43.5 | 46.8 | 43.9 | 46.8 | 43.8 | 47.2 | 43.4 | 44.3 | 42.0 |
| 17 Min | 34.0 | 31.4 | 42.9 | 42.0 | 41.5 | 42.5 | 40.0 | 43.0 | 40.0 | 42.1 | 39.0 | 41.5 |
| 18 Max | 36.8 | 31.9 | 41.3 | 42.2 | 41.6 | 42.3 | 41.0 | 41.5 | 41.0 | 40.5 | 39.2 | 39.5 |
| 18 Min | 34.1 | 31.8 | 39.5 | 41.5 | 39.5 | 40.9 | 39.0 | 41.2 | 38.5 | 40.0 | 37.5 | 39.5 |
| 19 Max | 39.9 | 31.8 | 47.4 | 40.5 | 48.5 | 40.5 | 49.0 | 41.5 | 46.6 | 41.0 | 45.9 | 40.1 |
| 19 Min | 32.2 | 31.7 | 36.0 | 40.0 | 35.2 | 40.0 | 34.5 | 39.6 | 33.9 | 38.0 | 32.9 | 37.0 |
| 20 Max | 41.0 | 32.4 | 46.5 | 42.0 | 49.0 | 42.5 | 55.4 | 49.9 | 50.0 | 46.7 | 51.8 | 40.0 |
| 20 Min | 35.0 | 31.2 | 35.6 | 38.0 | 39.0 | 38.9 | 37.8 | 39.0 | 37.5 | 37.0 | 36.0 | 37.2 |
| 22 Max | 42.9 | 31.9 | 48.8 | 44.5 | 48.0 | 45.0 | 46.7 | 45.4 | 48.5 | 45.2 | 47.2 | 44.0 |
| 22 Min | 40.3 | 31.9 | 46.2 | 44.3 | 45.5 | 44.9 | 44.0 | 44.9 | 43.9 | 44.9 | 42.3 | 44.8 |
| 23 Max | 39.8 | 32.0 | 50.9 | 43.8 | 51.0 | 43.5 | 52.2 | 43.9 | 51.8 | 42.8 | 49.4 | 42.8 |
| 23 Min | 34.3 | 31.8 | 38.9 | 42.4 | 37.5 | 42.3 | 35.8 | 42.3 | 35.8 | 41.5 | 34.4 | 40.0 |
| 24 Max | 45.0 | 31.9 | 56.5 | 43.0 | 57.0 | 44.3 | 58.1 | 45.2 | 57.0 | 45.1 | 53.8 | 45.2 |
| 24 Min | 38.5 | 31.7 | 45.3 | 43.7 | 45.3 | 43.8 | 45.1 | 43.6 | 44.8 | 43.9 | 44.0 | 43.4 |
| 25 Max | 42.9 | 31.8 | 55.3 | 45.0 | 56.1 | 45.1 | 56.9 | 45.2 | 57.8 | 45.4 | 55.0 | 45.0 |
| 25 Min | 37.0 | 31.2 | 41.9 | 44.1 | 41.2 | 44.2 | 40.0 | 44.1 | 39.5 | 43.5 | 38.9 | 42.3 |
| 26 Max | 47.1 | 31.9 | 57.5 | 45.5 | 58.6 | 46.9 | 61.5 | 47.3 | 61.1 | 47.0 | 59.1 | 47.9 |
| 26 Min | 41.2 | 31.8 | 49.0 | 45.5 | 49.0 | 45.9 | 48.9 | 46.2 | 48.8 | 46.1 | 47.9 | 45.4 |
| 27 Max | 42.0 | 31.9 | 57.5 | 47.5 | 58.2 | 47.7 | 58.0 | 48.3 | 57.4 | 48.0 | 54.0 | 48.1 |
| 27 Min | 40.0 | 31.8 | 47.2 | 47.0 | 48.0 | 47.3 | 46.3 | 47.3 | 46.6 | 47.1 | 45.0 | 46.4 |
| 29 Max | 37.8 | 32.0 | 45.0 | 44.9 | 45.1 | 44.9 | 45.5 | 44.5 | 45.2 | 44.0 | 44.0 | 42.0 |
| 29 Min | 37.2 | 31.9 | 42.6 | 44.4 | 42.5 | 44.1 | 41.8 | 44.0 | 41.8 | 43.6 | 40.0 | 42.4 |
| 30 Max | 39.5 | 31.8 | 50.0 | 43.7 | 50.0 | 43.9 | 50.9 | 44.6 | 50.0 | 45.0 | 50.1 | 44.5 |
| 30 Min | 35.9 | 31.6 | 48.8 | 42 9 | 37.2 | 42.8 | 36 8 | 42 4 | 36.9 | 42 0 | 36.0 | 41.0 |
| Monthly range | 2.57 | 0.28 | 7.03 | 0.69 | 8.29 | 0.93 | 10.33 | 1.55 | 9.85 | 1.39 | 5.23 | 1.00 |

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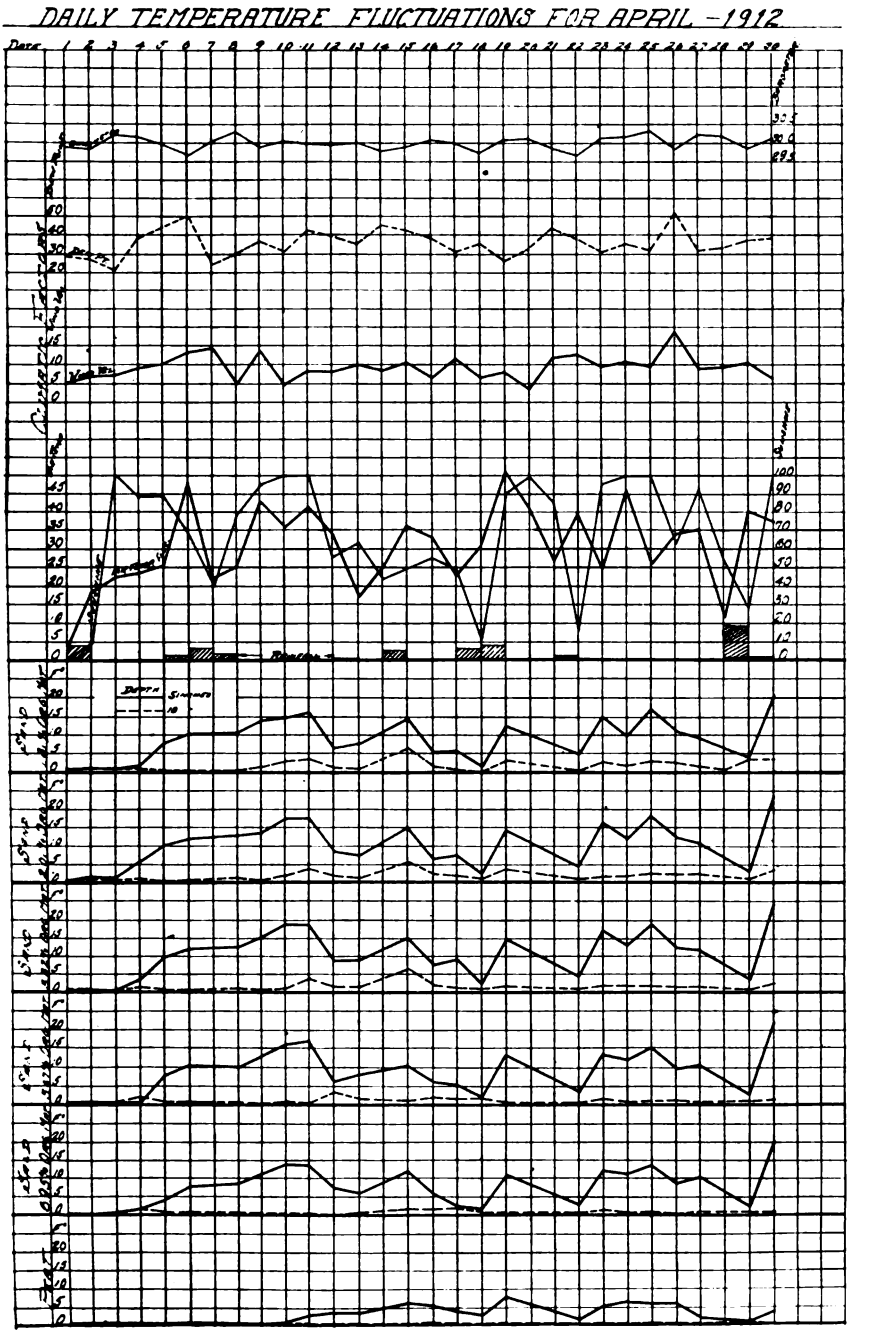


FIG. 41.

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TABLE 60. — EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, MAY, 1912.

| Date—Maximum, minimum. | Peat. | | 6.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat | | 2.01% Org Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 40.0 | 32.0 | 49.8 | 45.7 | 50.3 | 45.9 | 51.0 | 46.6 | 50.6 | 45.7 | 48.9 | 45.0 |
| 1 Min | 39.1 | 31.6 | 44.4 | 45.0 | 44.1 | 45.0 | 43.5 | 44.9 | 43.4 | 45.0 | 41.9 | 44.0 |
| 2 Max | 43.5 | 32.1 | 60.6 | 46.0 | 61.4 | 46.5 | 62.9 | 46.3 | 62.0 | 47.8 | 50.0 | 47.5 |
| 2 Min | 39.9 | 31.9 | 44.3 | 45.0 | 44.2 | 44.9 | 44.2 | 45.1 | 43.1 | 45.0 | 42.9 | 44.5 |
| 3 Max | 47.0 | 32.1 | 86.2 | 48.1 | 65.3 | 49.3 | 68.8 | 50.6 | 86.7 | 50.5 | 62.5 | 50.3 |
| 3 Min | 43.8 | 31.9 | 49.4 | 47.4 | 49.3 | 47.4 | 49.0 | 47.7 | 49.5 | 47.8 | 46.9 | 47.3 |
| 4 Max | 49.0 | 32.4 | 67.0 | 50.0 | 67.0 | 50.6 | 68.6 | 51.5 | 67.1 | 52.0 | 63.3 | 52.0 |
| 4 Min | 46.0 | 32.1 | 51.7 | 49.5 | 51.4 | 49.4 | 50.0 | 49.8 | 50.0 | 49.8 | 48.6 | 49.4 |
| 6 Max | 54.9 | 35.9 | 70.5 | 52.8 | 70.2 | 53.2 | 71.3 | 53.9 | 70.9 | 54.0 | 60.5 | 54.6 |
| 6 Min | 50.2 | 35.8 | 53.9 | 51.5 | 53.1 | 51.8 | 53.0 | 52.0 | 52 8 | 52.0 | 51.3 | 51.2 |
| 7 Max | 56.9 | 39.8 | 60.0 | 54.8 | 59.2 | 55.3 | 72.8 | 55.9 | 70.8 | 56.4 | 65.8 | 56.9 |
| 7 Min | 54.0 | 38.4 | 57.8 | 54.1 | 57.7 | 54.1 | 57.0 | 54.8 | 56.8 | 54.7 | 54.9 | 54.0 |
| 8 Max | 56.9 | 44.9 | 65.1 | 55.6 | 64.8 | 54.9 | 65.5 | 55.5 | 64.6 | 55.8 | 61.1 | 55.1 |
| 8 Min | 54.0 | 41.0 | 53.8 | 54.2 | 53.1 | 54.0 | 62.3 | 53.9 | 51.8 | 53.8 | 50.5 | 52.5 |
| 9 Max | 55.4 | 49.9 | 66.7 | 54.8 | 67.0 | 54.2 | 68.8 | 54.4 | 65.8 | 54.6 | 61.2 | 53.7 |
| 9 Min | 54.0 | 49.0 | 51.4 | 53.4 | 50.3 | 53.3 | 49.2 | 52.9 | 49.0 | 52.7 | 47.5 | 51.4 |
| 10 Max | 58.1 | 51.4 | 71.0 | 54.0 | 71.7 | 54.5 | 71.8 | 55.0 | 71.2 | 55.4 | 66.3 | 55.0 |
| 10 Min | 54.0 | 50.6 | 51.4 | 53.4 | 51.0 | 53.0 | 49.5 | 53.0 | 49.1 | 52.5 | 47.0 | 51.5 |
| 11 Max | 57.5 | 52.0 | 60.7 | 55.8 | 66.0 | 56.0 | 60.5 | 56.0 | 59.8 | 56.0 | 58.6 | 54.8 |
| 11 Min | 56.6 | 51.5 | 58.3 | 54.2 | 58.5 | 54.0 | 57.5 | 54.7 | 57.0 | 54.4 | 55.4 | 54.0 |
| 13 Max | 51.6 | 53.0 | 51.4 | 50.0 | 58.8 | 49.3 | 57.9 | 49.2 | 58.6 | 49.0 | 54.0 | 49.7 |
| 13 Min | 48.5 | 52.5 | 42.5 | 49.4 | 42.0 | 48.8 | 40.4 | 48.7 | 40.5 | 47.9 | 39.6 | 46.5 |
| 14 Max | 53.1 | 52.3 | 66.8 | 51.0 | 61.2 | 51.2 | 61.3 | 51.9 | 60.1 | 51.8 | 56.6 | 51.0 |
| 14 Min | 50.2 | 51.3 | 46.5 | 49.8 | 46.7 | 49.3 | 46.4 | 49.4 | 46.3 | 49.2 | 44.3 | 47.0 |
| 15 Max | 50.4 | 52.0 | 50.3 | 51.5 | 50.4 | 51.0 | 51.0 | 51.9 | 50.3 | 50.2 | 48.5 | 48.8 |
| 15 Min | 49.7 | 51.7 | 46.3 | 50.0 | 45.8 | 50.0 | 44.4 | 50.0 | 44.4 | 49.3 | 42.8 | 48 0 |
| 16 Max | 49.8 | 51.3 | 51.4 | 50.0 | 51.3 | 49.5 | 50.8 | 49.2 | 50.3 | 49.0 | 49.0 | 49.4 |
| 16 Min | 49.5 | 51.0 | 47.7 | 49.0 | 47.4 | 49.0 | 47.0 | 49.0 | 47.0 | 48.7 | 45.7 | 47.8 |
| 17 Max | 51.8 | 51.4 | 59.8 | 49.2 | 69.8 | 49.1 | 62.0 | 50.0 | 62.9 | 50.1 | 58.2 | 49.9 |
| 17 Min | 48.8 | 50.0 | 47.5 | 48.5 | 46.5 | 48.1 | 46.0 | 48.0 | 45.6 | 47.8 | 45.0 | 47.0 |
| 18 Max | 51.1 | 50.7 | 55.6 | 50.1 | 57.8 | 49.4 | 66.1 | 49.5 | 58.8 | 58.4 | 56.6 | 48.5 |
| 18 Min | 50.1 | 49 3 | 46.9 | 50.1 | 46.4 | 49.0 | 46.1 | 49.5 | 47.0 | 49.6 | 44.9 | 47.3 |
| 20 Max | 54.4 | 51.0 | 58.2 | 51.8 | 58.7 | 51.8 | 58.9 | 52.0 | 58.8 | 52.9 | 57.4 | 51.8 |
| 20 Min | 51.8 | 50.2 | 51.4 | 51.5 | 51.0 | 51.3 | 50.2 | 51.3 | 49.9 | 50.6 | 48.5 | 49.7 |
| 21 Max | 58.9 | 51.8 | 63.0 | 53.0 | 63.1 | 53.2 | 61.8 | 54.0 | 62.8 | 54.8 | 60.8 | 54.3 |
| 21 Min | 53.4 | 49.9 | 53.3 | 51.3 | 53.7 | 51.2 | 53.6 | 51.3 | 53.5 | 51.3 | 53.4 | 50.9 |
| 22 Max | 61.8 | 52.8 | 72.2 | 55.0 | 74.3 | 55.7 | 77.0 | 56.9 | 76.9 | 57.7 | 73.2 | 58.1 |
| 22 Min | 58.0 | 52.3 | 57.2 | 54 1 | 57.2 | 54.1 | 57.7 | 54.8 | 57.6 | 54.8 | 56.4 | 54.4 |
| 23 Max | 65.1 | 54.0 | 78.9 | 57.9 | 60.1 | 58.8 | 60.9 | 60.0 | 70.9 | 60.8 | 75.8 | 60.0 |
| 23 Min | 61 8 | 51.6 | 62 8 | 56.5 | 63.0 | 57.2 | 63.8 | 58.0 | 63.7 | 58.4 | 62.1 | 58.5 |
| 24 Max | 66.7 | 56.0 | 73.8 | 60.5 | 73.2 | 60.6 | 73.3 | 61.4 | 74.6 | 61.2 | 71.9 | 62.1 |
| 24 Min | 63.5 | 53.3 | 65.7 | 59.5 | 65.1 | 60.1 | 62.1 | 60.2 | 64.0 | 60.4 | 62.6 | 60.1 |
| 25 Max | 66.1 | 57.2 | 79.4 | 60.0 | 60.0 | 59.8 | 60.2 | 61.1 | 78.8 | 61.7 | 73.6 | 60.9 |
| 25 Min | 62.4 | 56 6 | 58.5 | 59.1 | 58.0 | 59.6 | 56.7 | 58.9 | 57.1 | 59.2 | 55.3 | 58.2 |
| 27 Max | 66.0 | 60.4 | 72.9 | 62.7 | 73.8 | 62.6 | 74.8 | 63.0 | 75.2 | 63.2 | 72.5 | 62.1 |
| 27 Min | 65.6 | 58.9 | 66.9 | 62.0 | 66.0 | 61.9 | 63.0 | 61.9 | 64.6 | 61.7 | 62.9 | 60.9 |
| 28 Max | 66.6 | 60.1 | 66.5 | 62.0 | 67.9 | 62.0 | 68.5 | 62.2 | 68.5 | 62.4 | 67.0 | 62.2 |
| 28 Min | 65.9 | 59.9 | 65.0 | 61.8 | 65.0 | 61.5 | 64.9 | 61.5 | 64.7 | 61.8 | 63.9 | 61.5 |
| 29 Max | 64.0 | 62.0 | 59.9 | 61.2 | 59.3 | 60.6 | 50.1 | 60.9 | 59.1 | 60.5 | 57.4 | 60.2 |
| 29 Min | 62.0 | 60.7 | 59.4 | 59.6 | 58.5 | 59.0 | 57.2 | 59.1 | 57.1 | 58.9 | 56.3 | 58.3 |
| 30 Max | 63.8 | 60.4 | 75.4 | 58.1 | 76.5 | 58.1 | 78.0 | 59.4 | 75.8 | 59.8 | 71.3 | 59.3 |
| 30 Min | 59.3 | 59.9 | 54.0 | 57.2 | 53.8 | 56.8 | 53.8 | 56.9 | 53.8 | 56.9 | 52.2 | 54.9 |
| 31 Max | 60.3 | 59.5 | 79.8 | 60.1 | 60.7 | 60.5 | 61.5 | 61.2 | 60.0 | 61.5 | 74.7 | 61.1 |
| 31 Min | 61.9 | 59.1 | 58.8 | 59.2 | 58.2 | 58.9 | 57.9 | 59.2 | 57.3 | 58.8 | 55.1 | 57.8 |
| Monthly range | 3.07 | 0.96 | 11.36 | 0.92 | 12.40 | 1.15 | 13.67 | 1.56 | 13.40 | 1.80 | 11.50 | 2.83 |

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FIG. 42.

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TABLE 61.—EFFECT OF ORGANIC MATTER ON TEMPERATURES OF SOILS. DAILY MAXIMUM AND MINIMUM, JUNE, 1912.

| Date—Maximum, minimum. | Peat. | | 6.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.01% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 60.7 | 61.0 | 61.3 | 62.9 | 61.9 | 63.3 | 62.2 | 64.0 | 61.1 | 64.3 | 77.0 | 63.8 |
| 1 Min | 64.6 | 59.7 | 61.8 | 61.7 | 63.2 | 61.2 | 62.4 | 61.5 | 62.0 | 61.0 | 59.8 | 60.1 |
| 3 Max | 67.1 | 61.0 | 77.7 | 61.9 | 78.3 | 61.8 | 79.0 | 62.6 | 78.1 | 63.6 | 75.6 | 62.9 |
| 3 Min | 63.8 | 61.0 | 60.2 | 61.0 | 59.5 | 60.3 | 59.2 | 60.3 | 58.9 | 60.0 | 57.7 | 59.3 |
| 4 Max | 66.4 | 61.5 | 72.0 | 62.9 | 70.9 | 62.5 | 71.0 | 62.8 | 72.0 | 62.7 | 60.3 | 62.3 |
| 4 Min | 64.6 | 61.3 | 61.8 | 62.1 | 60.9 | 61.6 | 59.8 | 61.5 | 59.7 | 61.2 | 58.2 | 60.5 |
| 5 Max | 64.3 | 61.8 | 72.9 | 61.9 | 72.0 | 61.0 | 73.5 | 61.1 | 72.6 | 61.5 | 60.1 | 60.8 |
| 5 Min | 61.9 | 61.3 | 56.4 | 60.5 | 54.9 | 59.8 | 54.4 | 59.8 | 54.8 | 59.3 | 53.3 | 58.1 |
| 6 Max | 60.6 | 61.3 | 75.2 | 62.0 | 75.1 | 61.9 | 75.5 | 63.0 | 73.9 | 63.9 | 70.3 | 62.3 |
| 6 Min | 64.0 | 61.2 | 63.2 | 61.4 | 62.2 | 60.8 | 62.0 | 61.3 | 62.0 | 61.0 | 60.6 | 60.4 |
| 7 Max | 65.6 | 61.4 | 74.3 | 62.5 | 74.4 | 62.0 | 74.9 | 61.9 | 72.6 | 61.5 | 68.1 | 60.3 |
| 7 Min | 62.3 | 61.2 | 58.8 | 61.3 | 58.0 | 60.8 | 56.2 | 60.5 | 55.8 | 60.0 | 54.0 | 58.4 |
| 8 Max | 64.4 | 61.3 | 72.0 | 62.0 | 71.9 | 61.8 | 72.0 | 61.8 | 71.0 | 61.7 | 60.8 | 60.5 |
| 8 Min | 61.6 | 61.2 | 58.0 | 61.0 | 57.1 | 60.5 | 55.8 | 60.0 | 54.9 | 59.1 | 52.5 | 57.9 |
| 10 Max | 60.7 | 62.3 | 77.9 | 64.0 | 78.0 | 63.6 | 77.9 | 63.6 | 76.4 | 63.0 | 72.5 | 62.2 |
| 10 Min | 64.2 | 61.0 | 61.4 | 62.0 | 60.5 | 61.7 | 59.0 | 61.2 | 58.2 | 60.5 | 56.3 | 59.1 |
| 11 Max | 60.6 | 61.3 | 77.1 | 63.8 | 77.7 | 63.5 | 78.0 | 63.3 | 77.0 | 63.4 | 73.7 | 62.8 |
| 11 Min | 64.0 | 61.3 | 62.1 | 62.8 | 61.8 | 62.1 | 60.3 | 62.0 | 59.8 | 61.4 | 58.9 | 60.0 |
| 12 Max | 68.7 | 62.0 | 77.5 | 64.2 | 77.5 | 64.2 | 77.1 | 64.5 | 76.0 | 64.5 | 73.5 | 64.5 |
| 12 Min | 66.4 | 61.8 | 67.5 | 64.0 | 66.9 | 63.9 | 66.0 | 63.9 | 65.8 | 63.4 | 64.1 | 62.9 |
| 13 Max | 68.3 | 62.5 | 78.0 | 64.9 | 78.0 | 64.3 | 78.1 | 64.2 | 77.0 | 64.4 | 74.0 | 64.1 |
| 13 Min | 65.3 | 62.3 | 62.4 | 63.9 | 61.7 | 63.4 | 60.2 | 63.1 | 59.8 | 62.5 | 58.0 | 61.7 |
| 14 Max | 66.8 | 63.0 | 66.7 | 65.1 | 66.5 | 65.0 | 66.0 | 64.9 | 65.3 | 64.3 | 63.5 | 63.5 |
| 14 Min | 65.4 | 63.0 | 64.3 | 63.7 | 64.0 | 63.0 | 62.8 | 63.0 | 62.3 | 62.4 | 60.9 | 62.0 |
| 15 Max | 68.2 | 62.8 | 75.8 | 63.9 | 75.2 | 63.3 | 74.8 | 64.0 | 74.0 | 64.4 | 72.0 | 64.5 |
| 15 Min | 64.8 | 62.7 | 64.0 | 62.4 | 64.2 | 62.2 | 64.7 | 62.2 | 64.2 | 61.9 | 63.4 | 61.2 |
| 17 Max | 69.1 | 63.7 | 78.7 | 65.0 | 78.4 | 64.9 | 79.0 | 65.1 | 78.0 | 65.0 | 74.7 | 65.2 |
| 17 Min | 66.1 | 63.2 | 62.5 | 63.9 | 62.0 | 63.7 | 60.9 | 63.8 | 60.8 | 63.3 | 59.8 | 62.5 |
| 18 Max | 66.5 | 63.3 | 74.5 | 64.6 | 75.6 | 64.5 | 76.1 | 64.3 | 74.8 | 63.8 | 71.1 | 63.1 |
| 18 Min | 64.9 | 63.2 | 61.9 | 63.7 | 61.1 | 63.4 | 59.4 | 63.2 | 58.9 | 62.7 | 57.0 | 61.5 |
| 19 Max | 66.0 | 63.5 | 75.3 | 64.5 | 75.3 | 64.5 | 75.8 | 65.0 | 74.8 | 65.1 | 71.4 | 64.6 |
| 19 Min | 65.2 | 62.8 | 63.4 | 63.7 | 62.8 | 63.3 | 61.7 | 63.4 | 61.2 | 63.0 | 59.8 | 62.0 |
| 20 Max | 67.5 | 63.1 | 76.2 | 64.2 | 76.3 | 64.0 | 77.0 | 64.4 | 76.2 | 64.6 | 73.1 | 64.2 |
| 20 Min | 65.0 | 63.0 | 62.9 | 63.7 | 62.0 | 63.4 | 60.7 | 63.4 | 60.2 | 62.9 | 58.6 | 61.9 |
| 21 Max | 66.4 | 63.5 | 76.0 | 64.6 | 76.0 | 64.5 | 77.9 | 64.9 | 76.8 | 65.0 | 73.2 | 64.4 |
| 21 Min | 65.5 | 63.0 | 63.2 | 64.3 | 62.1 | 63.9 | 60.9 | 63.9 | 60.1 | 63.5 | 58.5 | 62.5 |
| 22 Max | 66.5 | 63.6 | 81.0 | 65.0 | 81.1 | 65.0 | 81.7 | 65.5 | 80.2 | 65.8 | 77.0 | 65.1 |
| 22 Min | 65.4 | 63.2 | 62.5 | 64.3 | 61.7 | 64.0 | 60.4 | 63.9 | 59.5 | 63.2 | 57.9 | 62.2 |
| 24 Max | 70.5 | 64.3 | 78.6 | 67.0 | 78.7 | 67.1 | 78.9 | 67.1 | 78.0 | 67.0 | 75.7 | 66.0 |
| 24 Min | 68.4 | 64.0 | 67.1 | 66.4 | 66.3 | 66.3 | 65.2 | 66.2 | 64.6 | 65.9 | 63.0 | 65.0 |
| 25 Max | 71.7 | 65.0 | 83.0 | 67.4 | 83.0 | 67.1 | 83.5 | 67.5 | 83.1 | 68.0 | 80.4 | 66.0 |
| 25 Min | 68.3 | 64.9 | 66.8 | 66.4 | 66.2 | 66.0 | 65.2 | 66.0 | 64.8 | 65.7 | 63.3 | 65.0 |
| 26 Max | 72.9 | 65.4 | 80.8 | 68.0 | 80.2 | 68.1 | 80.3 | 68.9 | 79.9 | 69.0 | 78.0 | 66.1 |
| 26 Min | 69.7 | 65.0 | 68.9 | 67.4 | 68.2 | 67.2 | 67.5 | 67.4 | 67.0 | 67.0 | 65.4 | 66.5 |
| 27 Max | 71.9 | 66.0 | 79.6 | 68.2 | 79.7 | 68.1 | 79.9 | 68.4 | 79.3 | 68.0 | 77.5 | 68.1 |
| 27 Min | 70.0 | 65.5 | 68.6 | 67.4 | 68.0 | 67.4 | 67.1 | 67.8 | 66.6 | 67.3 | 65.4 | 66.7 |
| 28 Max | 73.3 | 66.0 | 82.2 | 68.0 | 81.5 | 67.9 | 81.5 | 68.4 | 81.0 | 68.8 | 78.2 | 69.0 |
| 28 Min | 69.5 | 65.8 | 67.9 | 67.0 | 67.2 | 66.8 | 66.2 | 67.0 | 66.0 | 66.6 | 64 7 | 66.2 |
| 29 Max | 72.6 | 66.5 | 79.6 | 69.0 | 79.7 | 68.9 | 80.7 | 69.0 | 80.2 | 68.9 | 78.3 | 68.2 |
| 29 Min | 71.5 | 63.8 | 70.0 | 65.8 | 69.7 | 66.0 | 68.9 | 66.6 | 68.3 | 63.9 | 66.8 | 64.0 |
| Monthly range | 2.71 | 0.33 | 13.51 | 0.97 | 14.20 | 1.20 | 15.44 | 1.47 | 14.92 | 2.66 | 13.48 | 2.52 |

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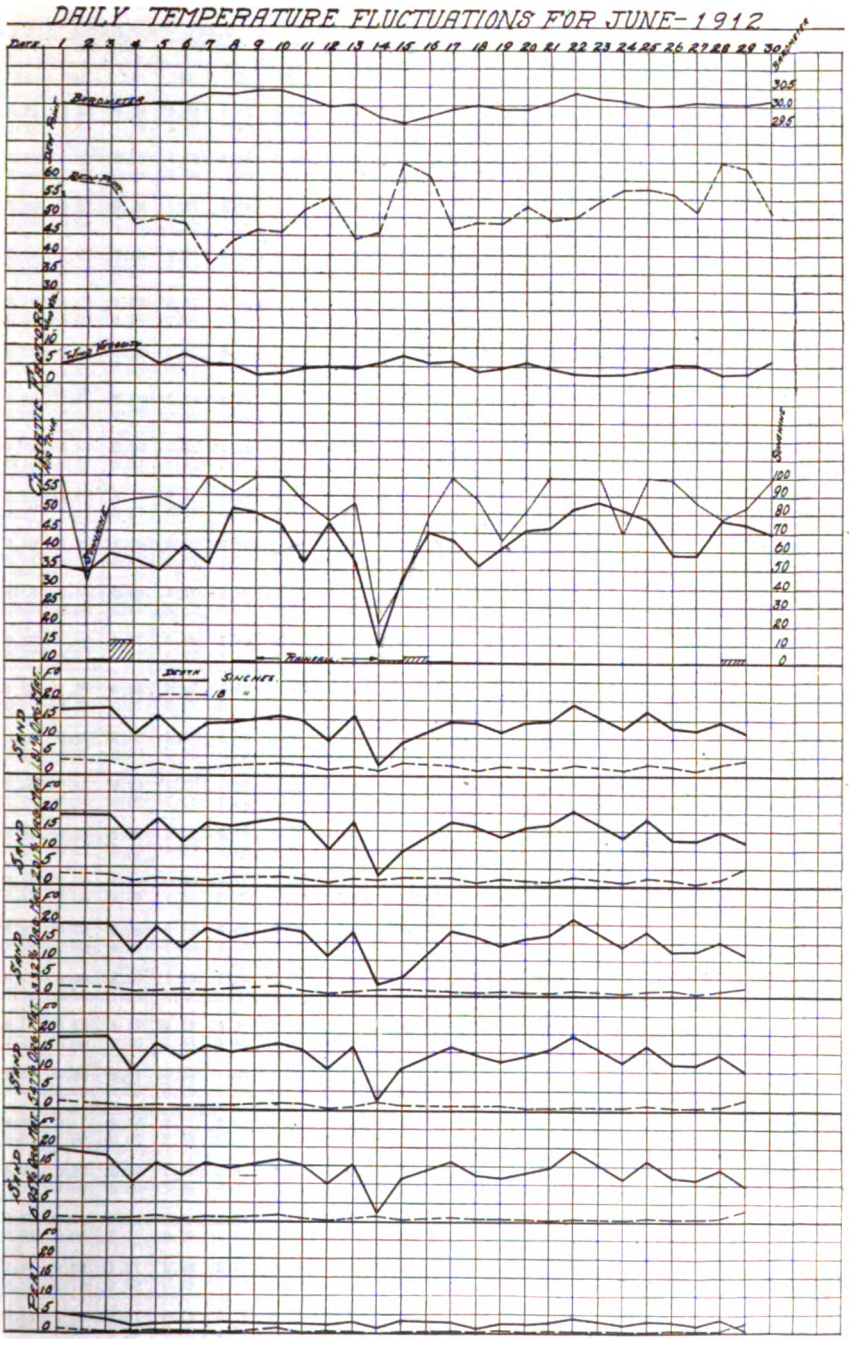


FIG. 43.

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TABLE 62.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, JULY, 1912.

| Date—Maximum, minimum. | Peat. | | 6.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.01% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 72.0 | 67.8 | 81.2 | 69.7 | 80.8 | 69.3 | 81.1 | 69.4 | 80.8 | 69.0 | 78.8 | 68.6 |
| 1 Min | 69.2 | 66.5 | 66.2 | 67.4 | 65.9 | 67.4 | 64.6 | 67.4 | 64.1 | 67.0 | 62.4 | 66.0 |
| 2 Max | 73.1 | 67.5 | 81.4 | 69.3 | 80.9 | 69.2 | 81.1 | 69.3 | 81.0 | 69.1 | 79.4 | 69.0 |
| 2 Min | 69.7 | 66.2 | 69.5 | 67.4 | 69.0 | 67.2 | 68.0 | 67.2 | 67.7 | 67.0 | 66.3 | 66.4 |
| 3 Max | 74.7 | 68.0 | 83.0 | 70.0 | 82.2 | 69.9 | 82.6 | 70.1 | 81.9 | 70.0 | 80.2 | 70.2 |
| 3 Min | 72.9 | 66.4 | 72 2 | 68.8 | 71.7 | 68.9 | 71.1 | 69.3 | 70.7 | 69.6 | 69.6 | 69.4 |
| 4 Max | 76.0 | 67.4 | 85.0 | 70.0 | 84.1 | 70.0 | 84.3 | 70.2 | 84.2 | 70.7 | 82.5 | 71.0 |
| 4 Min | 72.1 | 67.0 | 71.6 | 69.0 | 71.2 | 68.6 | 70.2 | 68.7 | 69.9 | 68.6 | 68.6 | 68.2 |
| 5 Max | 77.2 | 68.8 | 83.6 | 71.5 | 83.1 | 71.7 | 83.1 | 72.0 | 83.1 | 72.2 | 81.8 | 72.4 |
| 5 Min | 74.4 | 68.0 | 75.3 | 70.3 | 75.0 | 70.3 | 74.1 | 70.4 | 74.1 | 70.5 | 73.0 | 70.5 |
| 6 Max | 78.1 | 70.0 | 83.9 | 72.0 | 81.9 | 72.1 | 81.0 | 72.9 | 81.6 | 73.2 | 79.8 | 73.7 |
| 6 Min | 75.3 | 69.4 | 74.9 | 71.8 | 74.5 | 71.5 | 73.7 | 71.8 | 73.6 | 71.7 | 72.6 | 71.6 |
| 8 Max | 78.2 | 70.9 | 86.0 | 71.6 | 85.2 | 71.4 | 85.2 | 72.3 | 85.0 | 73.0 | 82.9 | 73.4 |
| 8 Min | 74.7 | 70.6 | 72.7 | 71.0 | 72.2 | 70.7 | 71.3 | 70.9 | 71.1 | 70.7 | 70.0 | 70.3 |
| 9 Max | 79.5 | 71.0 | 88.5 | 72.2 | 88.4 | 72.2 | 89.4 | 73.2 | 89.6 | 74.0 | 87.1 | 74.5 |
| 9 Min | 75.4 | 70 1 | 74.3 | 71.2 | 74.0 | 71.1 | 73.0 | 71.2 | 72.6 | 71.3 | 71.3 | 71.2 |
| 10 Max | 79.6 | 71.9 | 84.9 | 73.9 | 83.8 | 73.8 | 83.5 | 74.9 | 83.6 | 75.6 | 82.2 | 75.7 |
| 10 Min | 77.1 | 71.0 | 76.4 | 73.2 | 75.9 | 73.1 | 75.0 | 73.3 | 74.8 | 71.1 | 73 4 | 71.0 |
| 11 Max | 80.2 | 72.5 | 88.6 | 74.3 | 87.1 | 74.1 | 87.0 | 74.5 | 86.7 | 74.9 | 84.5 | 75.0 |
| 11 Min | 77.0 | 72.3 | 75.7 | 73.6 | 75.0 | 73.3 | 74.1 | 73.6 | 73.8 | 73.4 | 72.5 | 73.1 |
| 12 Max | 78.7 | 72.8 | 85.0 | 74.7 | 84.2 | 74.3 | 84.0 | 74.4 | 84.0 | 74.2 | 82.2 | 74.6 |
| 12 Min | 76.0 | 72.7 | 74.2 | 73.8 | 73.5 | 73.3 | 72.2 | 73.3 | 71.9 | 73.0 | 70.2 | 72.3 |
| 13 Max | 77.0 | 73.2 | 77.0 | 74.2 | 77.2 | 74.0 | 77.3 | 74.1 | 77.4 | 74.1 | 76.2 | 73.6 |
| 13 Min | 74.5 | 72.9 | 72.7 | 72.9 | 72.0 | 72.5 | 71.2 | 72.5 | 71.0 | 72.4 | 70.0 | 72.2 |
| 15 Max | 79.7 | 72.4 | 83.5 | 73.2 | 83.1 | 73.2 | 85.3 | 74.9 | 84.6 | 75.1 | 82.1 | 76.1 |
| 15 Min | 77.2 | 72.3 | 75.0 | 72.7 | 74.6 | 72.7 | 75.0 | 73.2 | 75.0 | 73.6 | 74.0 | 73.4 |
| 16 Max | 76.3 | 72.0 | 83.7 | 72.0 | 84.3 | 72.3 | 85.2 | 72.4 | 84.8 | 72.0 | 81.0 | 71.2 |
| 16 Min | 72.4 | 72.0 | 65.9 | 71.0 | 64.3 | 70.7 | 63.0 | 70.9 | 63.0 | 70.3 | 61.6 | 69.1 |
| 17 Max | 78.2 | 72.0 | 87.1 | 72.3 | 87.9 | 72.3 | 88.5 | 73.2 | 87.9 | 73.5 | 84.3 | 73.2 |
| 17 Min | 74.3 | 71.7 | 71.9 | 71.3 | 71.2 | 71.2 | 70.7 | 71.7 | 70.3 | 71.3 | 67.7 | 70 0 |
| 18 Max | 75.0 | 72.0 | 72.2 | 73.2 | 71.8 | 73.2 | 71.0 | 73.4 | 70.2 | 73.2 | 68.9 | 72.9 |
| 18 Min | 72.9 | 71 8 | 71.3 | 71.8 | 70.8 | 71.4 | 69.3 | 71.4 | 69.0 | 71.0 | 67.7 | 69.8 |
| 19 Max | 70.9 | 71.4 | 78.9 | 69.4 | 77.0 | 68.7 | 77.0 | 68.6 | 76.1 | 67.3 | 73.6 | 66.3 |
| 19 Min | 66 8 | 70.2 | 59.3 | 67.4 | 57.9 | 66.5 | 56.0 | 66.1 | 55.8 | 65.2 | 54.5 | 63.7 |
| 20 Max | 68.7 | 70.0 | 66.3 | 68.0 | 66.1 | 67.8 | 65.9 | 67.5 | 65.3 | 67.0 | 63.8 | 65.5 |
| 20 Min | 68.0 | 69.4 | 64.3 | 66.8 | 64.0 | 65.3 | 63.1 | 66.2 | 62.8 | 65.9 | 61.5 | 64.9 |
| 22 Max | 70.0 | 67.7 | 78.0 | 65.4 | 79.4 | 65.3 | 81.2 | 66.2 | 80.3 | 66.6 | 77.8 | 66.7 |
| 22 Min | 65.6 | 66.3 | 62 3 | 64.5 | 62.2 | 64.1 | 61.8 | 64.2 | 61.7 | 64.0 | 61.7 | 63.4 |
| 23 Max | 69.4 | 66.6 | 72.3 | 66.8 | 73.3 | 66.9 | 75.4 | 67.6 | 74.4 | 67.8 | 71.9 | 67.4 |
| 23 Min | 68.0 | 66.5 | 64.9 | 66.2 | 64.4 | 66.2 | 64.4 | 66.7 | 64.3 | 66.5 | 63.3 | 66.0 |
| 24 Max | 73.0 | 67.4 | 79.6 | 67.7 | 79.2 | 68.1 | 80.1 | 69.0 | 79.8 | 69.4 | 78.6 | 69.6 |
| 24 Min | 68.7 | 67.1 | 68.7 | 66.9 | 68.9 | 67.0 | 69.1 | 67.5 | 68.9 | 67.5 | 68 0 | 67.1 |
| 25 Max | 74.9 | 67.8 | 82.6 | 69.3 | 82.6 | 69.9 | 82.4 | 71.0 | 83.6 | 71.0 | 80.8 | 71.9 |
| 25 Min | 72.2 | 67.5 | 70.6 | 68.8 | 70.2 | 68.9 | 70.0 | 69.2 | 70.0 | 69.2 | 69.2 | 69.2 |
| 26 Max | 71.2 | 69.0 | 79.0 | 70.2 | 78.3 | 70.0 | 78.5 | 70.3 | 77.5 | 70.0 | 74.8 | 69.4 |
| 26 Min | 69.7 | 68.1 | 67 3 | 68.8 | 66.3 | 68.7 | 66.0 | 69.1 | 66.0 | 68.8 | 65.1 | 68.0 |
| 27 Max | 71.9 | 67.8 | 84.2 | 68.9 | 83.3 | 68.5 | 83.3 | 68.8 | 82.4 | 69.0 | 77.0 | 67.9 |
| 27 Min | 67.7 | 67 0 | 64.1 | 67.5 | 63.0 | 67.0 | 61.7 | 67.0 | 61.5 | 66.6 | 60 3 | 65.5 |
| 29 Max | 70.9 | 68.3 | 75.0 | 69.3 | 74.7 | 68.9 | 74.8 | 68.9 | 70.1 | 68.6 | 74.1 | 69.1 |
| 29 Mine | 67.9 | 68.1 | 65.3 | 68.1 | 64 7 | 67.8 | 63.6 | 67.6 | 63.6 | 67.2 | 62.8 | 66 1 |
| 30 Max | 70 0 | 68.2 | 71.2 | 68.0 | 70.2 | 67.4 | 71.5 | 67.8 | 71.3 | 69 2 | 69.5 | 67.9 |
| 30 Min | 67.3 | 68.0 | 62.5 | 67.0 | 62.0 | 66.2 | 61.5 | 66.3 | 62.0 | 66.1 | 61.0 | 65.2 |
| 31 Max | 69.0 | 68.1 | 73.6 | 68.9 | 72.5 | 68.4 | 73.2 | 68.3 | 74 7 | 68.4 | 73.0 | 68.1 |
| 31 Min | 65.7 | 67.5 | 60.2 | 65.7 | 59.2 | 65.1 | 58.1 | 65.1 | 58.3 | 64.7 | 57.6 | 63.6 |
| Monthly range | 2.96 | 0.64 | 11.25 | 1.10 | 11.40 | 1.25 | 12.63 | 1.51 | 12.83 | 1.90 | 12.57 | 2.20 |

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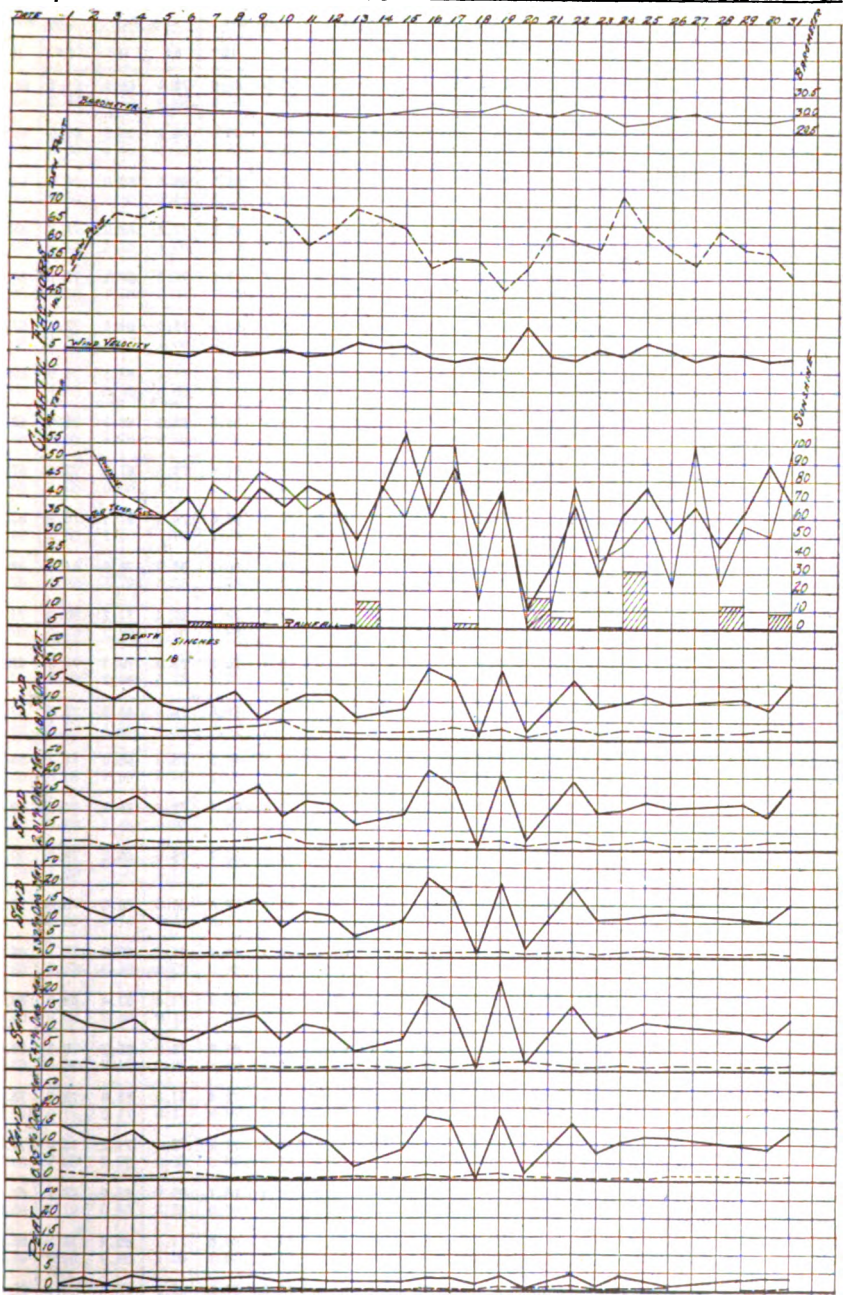


FIG. 44.

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TABLE 63.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, AUGUST, 1912.

| Date—Maximum, minimum. | Peat. | | 8.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.61% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 67.6 | 67.3 | 73.4 | 68.0 | 71.6 | 65.4 | 73.3 | 65.6 | 73.4 | 65.9 | 71.1 | 65.4 |
| 1 Min | 65.0 | 66.2 | 59.8 | 65.0 | 58.7 | 64.3 | 58.3 | 64.5 | 59.0 | 64.4 | 58.2 | 63.6 |
| 2 Max | 67.0 | 66.2 | 68.7 | 65.9 | 67.3 | 65 2 | 67.1 | 65.6 | 68.8 | 65.5 | 65.0 | 65.8 |
| 2 Min | 65.2 | 66.1 | 62.8 | 65.1 | 61.8 | 64.4 | 61.2 | 64.8 | 61.5 | 64.6 | 60.5 | 63.8 |
| 3 Max | 64.3 | 65.8 | 67.1 | 64.4 | 60.1 | 63.5 | 60.8 | 63.3 | 68.6 | 63.9 | 64.9 | 62.2 |
| 3 Min | 62.3 | 65.3 | 56.9 | 63.2 | 55.2 | 62.3 | 54.2 | 62.3 | 54.2 | 61.9 | 53.2 | 61.4 |
| 5 Max | 68.7 | 64.3 | 78.1 | 65.1 | 76.0 | 65.0 | 76.6 | 65.8 | 77.3 | 68.0 | 73.7 | 65.7 |
| 5 Min | 64.0 | 64.0 | 61.0 | 64.0 | 59.9 | 63.6 | 59.2 | 63.7 | 59.1 | 63.4 | 57.8 | 62.6 |
| 6 Max | 69.4 | 64.5 | 77.3 | 66.1 | 77.4 | 69.2 | 77.2 | 67.0 | 76.8 | 67.1 | 73.7 | 68.4 |
| 6 Min | 65.9 | 64.5 | 64.6 | 65.8 | 63.7 | 65.3 | 63.0 | 65.4 | 63.0 | 65.1 | 61.5 | 64.2 |
| 7 Max | 70.3 | 65.0 | 76 2 | 67.3 | 75.6 | 67.5 | 76.1 | 66.2 | 75.9 | 66.2 | 72.4 | 67.7 |
| 7 Min | 67.6 | 64.9 | 67.3 | 66.9 | 67.0 | 66.7 | 66.3 | 66.9 | 66.1 | 66.6 | 65.1 | 65.8 |
| 8 Max | 71.4 | 65.5 | 76.8 | 67.6 | 78.8 | 67.6 | 78.2 | 66.2 | 77.9 | 66.3 | 75.9 | 66.4 |
| 8 Min | 68.6 | 65.3 | 67.9 | 67.2 | 67.6 | 67.0 | 67.0 | 67.2 | 66.6 | 66.6 | 65.7 | 66.0 |
| 9 Max | 71.3 | 66.1 | 73.3 | 68.0 | 74.3 | 68.6 | 75.9 | 68.5 | 75.0 | 68.8 | 73.6 | 68.6 |
| 9 Min | 69.5 | 65.4 | 68.7 | 67.4 | 68.0 | 67.3 | 67.8 | 67.5 | 67.8 | 67.4 | 66.9 | 66.9 |
| 10 Max | 70.1 | 66.0 | 74.4 | 67.8 | 74.1 | 67.6 | 73.4 | 67.6 | 73.6 | 67.2 | 72.8 | 67.1 |
| 10 Min | 67.9 | 66.0 | 65.3 | 66.5 | 64.8 | 66.2 | 64.0 | 66.2 | 64.1 | 66.0 | 63.2 | 65.8 |
| 12 Max | 71.0 | 66.5 | 76.8 | 66.2 | 78.2 | 66.0 | 79.0 | 66.6 | 79.6 | 67.1 | 78.0 | 67.8 |
| 12 Min | 67.0 | 65.5 | 64.6 | 65.1 | 64.5 | 65.0 | 64.2 | 65.1 | 64.1 | 65.1 | 63.3 | 64.8 |
| 13 Max | 73.6 | 66.4 | 81.7 | 67.7 | 81.5 | 67.0 | 83.8 | 66.2 | 83.8 | 70.0 | 81.7 | 70.8 |
| 13 Min | 70.0 | 65.6 | 69.0 | 66.4 | 68.8 | 66.4 | 69.0 | 67.2 | 69.0 | 67.5 | 68.2 | 67.6 |
| 14 Max | 74.5 | 68.0 | 83.3 | 69.4 | 83.0 | 69.4 | 83.9 | 70.5 | 83.4 | 71.2 | 80.6 | 71.2 |
| 14 Min | 71.1 | 66.6 | 69.2 | 68.5 | 67.9 | 68.3 | 67.7 | 69.0 | 68.0 | 69.2 | 67.6 | 69.0 |
| 15 Max | 72.0 | 67.7 | 79.8 | 70.1 | 79.6 | 70.0 | 79.4 | 70.2 | 78.0 | 70.1 | 74.8 | 68.1 |
| 15 Min | 69.3 | 67.4 | 66.0 | 68.4 | 64.7 | 68.3 | 63.6 | 68.5 | 63.5 | 68.2 | 63.0 | 67.2 |
| 16 Max | 71.6 | 67.8 | 80.1 | 69.1 | 80.2 | 68.4 | 79.8 | 68.4 | 76.4 | 68.8 | 75.8 | 67.5 |
| 16 Min | 67.6 | 67.2 | 64.1 | 67.6 | 63.0 | 67.0 | 61.8 | 67.0 | 61.5 | 66.1 | 60.5 | 65.0 |
| 17 Max | 69.2 | 67.6 | 73.2 | 68.9 | 73.3 | 69.2 | 73.3 | 68.5 | 73.0 | 68.9 | 71.1 | 69.4 |
| 17 Min | 68.0 | 67.1 | 66.0 | 67.2 | 65.1 | 67.0 | 64.0 | 67.1 | 63.6 | 66.4 | 62.6 | 65.3 |
| 19 Max | 71.1 | 67.1 | 73.5 | 69.8 | 73.4 | 69.2 | 73.0 | 69.4 | 72.4 | 68.3 | 71.3 | 69.8 |
| 19 Min | 70.3 | 67.0 | 70.4 | 68.3 | 70.1 | 68.1 | 69.4 | 68.7 | 69.4 | 68.5 | 68.7 | 68.1 |
| 20 Max | 72.2 | 67.4 | 77.0 | 68.3 | 77.8 | 68.2 | 79.0 | 68.7 | 79.5 | 69.0 | 78.2 | 69.2 |
| 20 Min | 69.5 | 67.0 | 68.0 | 67.4 | 67.5 | 67.3 | 67.4 | 67.5 | 67.3 | 67.2 | 66.1 | 67.0 |
| 21 Max | 73.2 | 68.3 | 78.2 | 69.0 | 79.0 | 69.9 | 80.4 | 70.6 | 80.6 | 70.6 | 78.6 | 70.8 |
| 21 Min | 69.7 | 67.4 | 66.6 | 67.8 | 66.2 | 67.4 | 66.0 | 67.9 | 65.9 | 67.9 | 65.2 | 67.5 |
| 22 Max | 71.0 | 68.7 | 72.6 | 69.8 | 74.1 | 69.2 | 76.3 | 69.7 | 76.1 | 69.0 | 73.7 | 69.4 |
| 22 Min | 69.8 | 68.3 | 66.0 | 68.5 | 66.0 | 68.1 | 65.8 | 68.9 | 65.4 | 68.9 | 64.9 | 68.2 |
| 23 Max | 66.6 | 68.4 | 71.4 | 67.8 | 71.4 | 67.5 | 71.7 | 67.9 | 71.4 | 67.4 | 69.0 | 68.2 |
| 23 Min | 66.3 | 67.2 | 62.0 | 66.3 | 61.5 | 65.6 | 61.0 | 66.7 | 61.0 | 66.2 | 59.9 | 65.3 |
| 24 Max | 68.1 | 67.5 | 78.4 | 68.6 | 79.4 | 65.9 | 80.0 | 69.0 | 79.6 | 69.2 | 76.3 | 69.0 |
| 24 Min | 64.3 | 66.2 | 60.1 | 64.8 | 59.8 | 64.3 | 59.4 | 64.8 | 59.6 | 64.3 | 58.4 | 63.2 |
| 26 Max | 76.0 | 67.6 | 83.7 | 71.3 | 83.1 | 71.9 | 82.3 | 72.4 | 81.8 | 73.0 | 79.0 | 73.1 |
| 26 Min | 72.7 | 65.9 | 72.6 | 70.0 | 72.2 | 70.2 | 71.6 | 70.9 | 71.9 | 71.0 | 71.0 | 70.8 |
| 27 Max | 72.8 | 69.0 | 80.9 | 72.0 | 80.9 | 71.8 | 78.8 | 71.5 | 78.0 | 71.2 | 75.0 | 70.7 |
| 27 Min | 70.2 | 68.4 | 66.5 | 70.2 | 65.3 | 70.1 | 64.2 | 70.0 | 63.8 | 69.3 | 62.7 | 68.2 |
| 28 Max | 76.0 | 69.0 | 86.1 | 70.0 | 85.8 | 69.8 | 85.0 | 69.7 | 85.6 | 68.9 | 83.7 | 67.8 |
| 28 Min | 66.9 | 67.8 | 63.2 | 66.1 | 63.2 | 66.9 | 62.8 | 66.6 | 62.3 | 66.0 | 61.0 | 65.0 |
| 29 Max | 67.7 | 67.6 | 79.8 | 68.3 | 71.0 | 68.0 | 71.1 | 65.8 | 71.7 | 65.4 | 70.5 | 65.1 |
| 29 Min | 65.4 | 67.3 | 62.0 | 65.4 | 61.8 | 65.3 | 61.0 | 65.3 | 60.7 | 64.9 | 60.0 | 63.8 |
| 30 Max | 64.3 | 66.3 | 63.4 | 64.8 | 63.5 | 64.3 | 63.0 | 64.0 | 63.0 | 63.6 | 63.1 | 62.0 |
| 30 Min | 62.3 | 64.9 | 57.0 | 62.6 | 55.7 | 62.1 | 54.8 | 62.2 | 55.4 | 61.8 | 55.3 | 61.0 |
| 31 Max | 69.2 | 64.7 | 80.2 | 63.8 | 80.9 | 64.2 | 82.0 | 65.5 | 81.6 | 65.0 | 79.8 | 66.8 |
| 31 Min | 62.7 | 64.3 | 60.6 | 62.2 | 61.1 | 61.8 | 61.3 | 62.3 | 61.3 | 62.1 | 60.6 | 61.5 |
| Monthly range | 2.82 | 0.63 | 10.73 | 1.22 | 11.29 | 1.37 | 12.34 | 1.49 | 12.07 | 1.85 | 10.77 | 2.15 |

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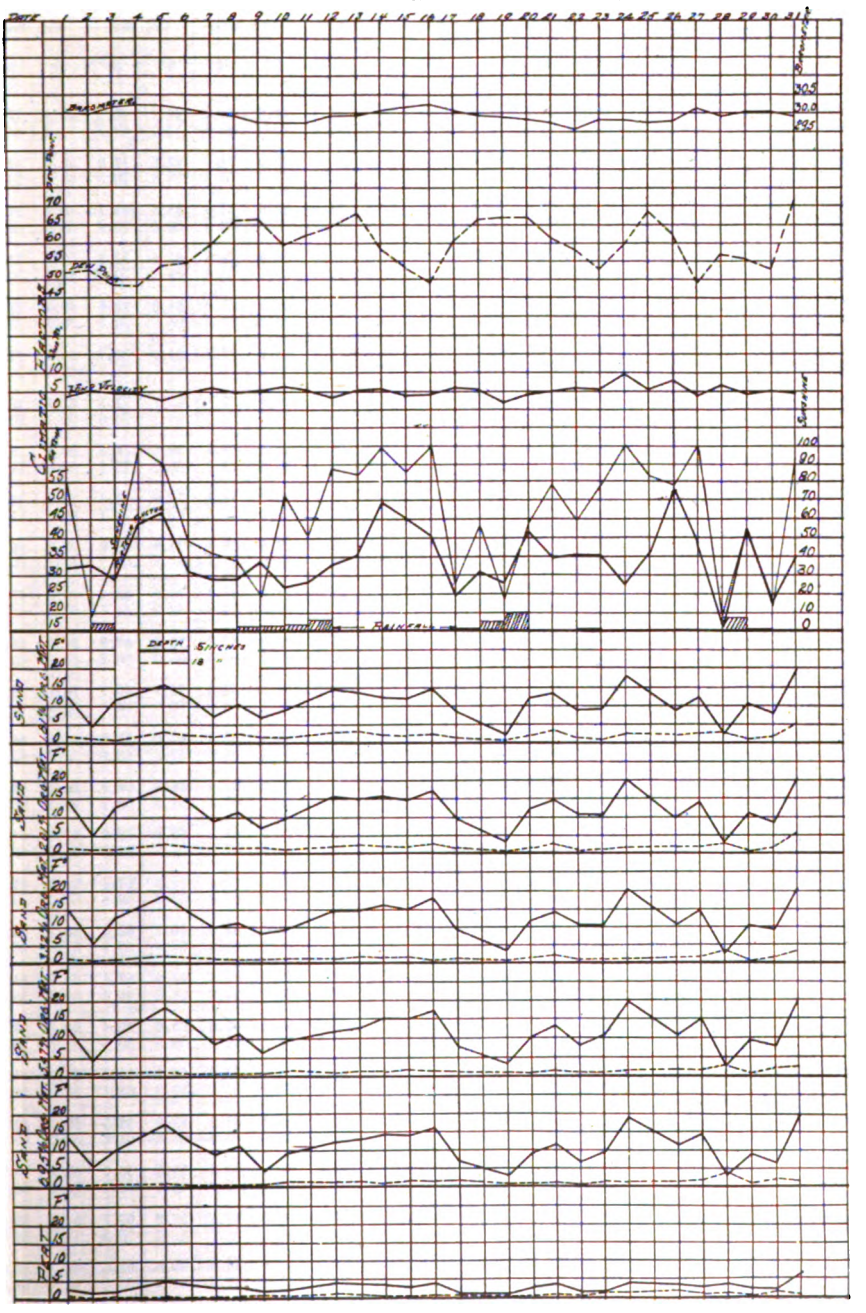


FIG. 45.

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TABLE 64.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, SEPTEMBER, 1912.

| Date—Maximum, minimum. | Peat. | | 6.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.01% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 2 Max | 78.0 | 66.2 | 84.6 | 69.9 | 85.1 | 70.7 | 84.9 | 71.8 | 84.1 | 72.1 | 81.9 | 72.6 |
| 2 Min | 71.5 | 65.8 | 72.2 | 68.7 | 72.0 | 69.0 | 72.0 | 69.6 | 72.0 | 69.7 | 71.4 | 69.7 |
| 3 Max | 75.9 | 67.1 | 84.0 | 70.5 | 84.1 | 70.9 | 83.5 | 71.5 | 82.8 | 72.0 | 80.0 | 72.9 |
| 3 Min | 72.3 | 66.6 | 70.9 | 70.0 | 69.8 | 70.0 | 68.8 | 70.3 | 68.8 | 70.1 | 68.2 | 70.0 |
| 4 Max | 75.2 | 69.0 | 82.2 | 71.6 | 82.8 | 71.5 | 82.8 | 71.6 | 81.8 | 71.7 | 79.4 | 71.7 |
| 4 Min | 72.7 | 68.3 | 70.9 | 70.8 | 70.0 | 71.0 | 69.0 | 70.8 | 69.0 | 70.8 | 68.0 | 69.9 |
| 5 Max | 76.1 | 69.4 | 80.6 | 71.4 | 82.3 | 71.8 | 84.0 | 72.5 | 82.6 | 72.6 | 79.3 | 72.6 |
| 5 Min | 72.8 | 69.3 | 70.4 | 70.4 | 70.0 | 70.4 | 69.4 | 70.6 | 69.2 | 70.3 | 68.1 | 70.0 |
| 6 Max | 76.0 | 69.7 | 84.2 | 71.4 | 84.7 | 71.4 | 84.3 | 72.4 | 84.0 | 72.8 | 83.4 | 73.1 |
| 6 Min | 72.8 | 69.5 | 69.7 | 70.7 | 69.4 | 70.6 | 68.8 | 70.8 | 68.8 | 70.4 | 68.0 | 70.1 |
| 7 Max | 76.3 | 70.1 | 85.2 | 72.0 | 85.8 | 72.2 | 84.6 | 72.2 | 83.6 | 72.7 | 81.9 | 73.0 |
| 7 Min | 73.0 | 69.9 | 70.2 | 71.4 | 69.3 | 71.3 | 68.0 | 71.3 | 68.7 | 71.3 | 68 5 | 71 2 |
| 9 Max | 75.8 | 70.0 | 85.7 | 72.1 | 86.5 | 72.7 | 86.6 | 72.7 | 85.7 | 72.7 | 83.2 | 72.6 |
| 9 Min | 72.0 | 69.3 | 71.0 | 70.8 | 70.4 | 70.8 | 69.3 | 71.0 | 69.3 | 70.8 | 68.7 | 70.1 |
| 10 Max | 76.6 | 70.4 | 85.4 | 73.0 | 86.2 | 74.0 | 86.2 | 73.6 | 85.5 | 74.0 | 83.2 | 73.8 |
| 10 Min | 73.0 | 70.1 | 70.9 | 72.3 | 70.0 | 72.3 | 68.8 | 72 0 | 69.0 | 72.1 | 68.0 | 71.5 |
| 11 Max | 74.2 | 71.0 | 75.0 | 73.3 | 75.3 | 73.4 | 75.1 | 73.6 | 74.9 | 73.1 | 73.6 | 72.4 |
| 11 Min | 72.1 | 70.9 | 71.3 | 72.5 | 70.3 | 72.4 | 69.3 | 72.5 | 69.4 | 72.1 | 68.8 | 71.4 |
| 12 Max | 70.1 | 70.8 | 73.0 | 70.0 | 73.3 | 69.7 | 73.9 | 69.4 | 73.9 | 69.9 | 73.7 | 68.6 |
| 12 Min | 67.0 | 70.2 | 59.2 | 68.4 | 58.3 | 68.1 | 57.0 | 67.7 | 57.8 | 67.2 | 57.2 | 66.0 |
| 13 Max | 68.4 | 69.6 | 73.0 | 67.9 | 73.1 | 67.5 | 74.8 | 67.7 | 75.0 | 68.1 | 73.0 | 67.7 |
| 13 Min | 66.0 | 69.1 | 60.2 | 66.9 | 60.1 | 66.8 | 59.2 | 66.8 | 60.3 | 66.7 | 59.4 | 65.7 |
| 14 Max | 67.7 | 68.2 | 70.0 | 67.2 | 70.4 | 67.0 | 70.5 | 67.7 | 70.3 | 67.8 | 68.0 | 67.6 |
| 14 Min | 66.1 | 67.7 | 64.5 | 66.1 | 64.2 | 66.0 | 64.4 | 66.5 | 65.0 | 66.2 | 64.2 | 65.5 |
| 16 Max | 67.5 | 67.0 | 71.3 | 66.2 | 71.8 | 66.0 | 71.2 | 65.8 | 71.5 | 65.7 | 70.0 | 65.4 |
| 16 Min | 64.4 | 66.7 | 58.5 | 65.1 | 57.8 | 64.7 | 56.1 | 64.7 | 56.6 | 64.1 | 56.1 | 63.2 |
| 17 Max | 65.1 | 66.7 | 62.7 | 65.7 | 62.4 | 65.4 | 62.1 | 65.3 | 62.0 | 65.6 | 61.5 | 64.4 |
| 17 Min | 63.1 | 66 2 | 60.1 | 64.2 | 59.4 | 64.0 | 58.4 | 64 0 | 59.0 | 63.6 | 58.2 | 62.8 |
| 18 Max | 64.8 | 65.8 | 66.5 | 63.8 | 66.4 | 63.7 | 67.0 | 63.9 | 66.4 | 64.0 | 65.4 | 63.6 |
| 18 Min | 63.1 | 65.0 | 61.4 | 63.4 | 61.4 | 63.3 | 61.1 | 63.3 | 61.1 | 63.2 | 60.5 | 62.4 |
| 19 Max | 62.0 | 65.1 | 60.3 | 63.7 | 59.9 | 63.6 | 60.3 | 63.3 | 60.6 | 63.0 | 58.9 | 61.7 |
| 19 Min | 60.7 | 64.8 | 55.6 | 62.4 | 55.1 | 62.4 | 54.4 | 62.2 | 54.6 | 61.9 | 54.2 | 60.6 |
| 20 Max | 61.1 | 64.2 | 64.4 | 61.7 | 64.6 | 61.1 | 65.2 | 61.4 | 65.4 | 61.3 | 63.9 | 60.8 |
| 20 Min | 59.0 | 62 8 | 55.1 | 60.8 | 54.5 | 60.5 | 54.5 | 60.4 | 54.3 | 59.8 | 53.6 | 59.1 |
| 21 Max | 63.3 | 63.3 | 67.4 | 62.2 | 67.6 | 61.9 | 69.4 | 63.9 | 70.2 | 63.4 | 66.7 | 63.3 |
| 21 Min | 60.2 | 62.5 | 57.8 | 60.9 | 58.2 | 61.2 | 58.0 | 61.4 | 57.9 | 60.9 | 57.5 | 60.6 |
| 23 Max | 62.1 | 63.4 | 66.4 | 62.2 | 67.3 | 61.6 | 68.3 | 62.1 | 67.9 | 62.0 | 65.6 | 61.7 |
| 23 Min | 57.3 | 62.2 | 52.5 | 60.4 | 52.3 | 59.7 | 50.6 | 59.8 | 51.4 | 59.4 | 51.3 | 58.1 |
| 24 Max | 60.4 | 61.6 | 64.6 | 61.0 | 65.5 | 60.5 | 65.2 | 60.6 | 65.8 | 60.4 | 64.7 | 59.9 |
| 24 Min | 58.3 | 61.2 | 54.5 | 60.2 | 54.6 | 59.5 | 54.1 | 59.8 | 54.5 | 59.4 | 53.7 | 58.6 |
| 25 Max | 61.9 | 61.6 | 68.2 | 60.9 | 69.3 | 61.3 | 70.5 | 61.8 | 69.6 | 61.6 | 71.7 | 61.3 |
| 25 Min | 61.2 | 61.0 | 59.4 | 60.6 | 59.6 | 60.7 | 59.4 | 61.3 | 59.6 | 61.1 | 59.2 | 60 6 |
| 26 Max | 62.2 | 62.1 | 62.1 | 62.6 | 61.4 | 62.8 | 61.4 | 63.2 | 62.2 | 63.3 | 60.9 | 62.8 |
| 26 Min | 60.6 | 61.5 | 57.3 | 61.6 | 56.0 | 61.4 | 55.1 | 61.9 | 56.6 | 61.8 | 56.7 | 60.9 |
| 27 Max | 56.1 | 62.6 | 58.0 | 60.2 | 58.1 | 59.7 | 59.5 | 59.4 | 58.5 | 59.0 | 55.9 | 57.5 |
| 27 Min | 53.6 | 61 8 | 47.0 | 57.4 | 46.0 | 57.5 | 45.3 | 57.3 | 45.5 | 56.7 | 45.1 | 55.1 |
| 28 Max | 54.4 | 60.3 | 52.3 | 57.0 | 52.1 | 57.5 | 52.2 | 57.3 | 52.5 | 57.2 | 51.5 | 55.3 |
| 28 Min | 53.7 | 59.9 | 50.4 | 56.9 | 49.9 | 56.8 | 49.0 | 56.7 | 49.3 | 56.8 | 48.7 | 54.8 |
| 30 Max | 52.9 | 57.5 | 53.9 | 54.8 | 53.8 | 54.8 | 54.4 | 53.9 | 55.0 | 53.6 | 54.1 | 53.6 |
| 30 Min | 50.7 | 57.4 | 44.9 | 54.5 | 44.3 | 54.0 | 43.2 | 53.7 | 43.8 | 53.0 | 42.9 | 51.5 |
| Monthly range | 2.55 | 0.58 | 9.80 | 1.00 | 10.65 | 0.43 | 11.80 | 1.25 | 11.23 | 1.56 | 10.31 | 1.97 |

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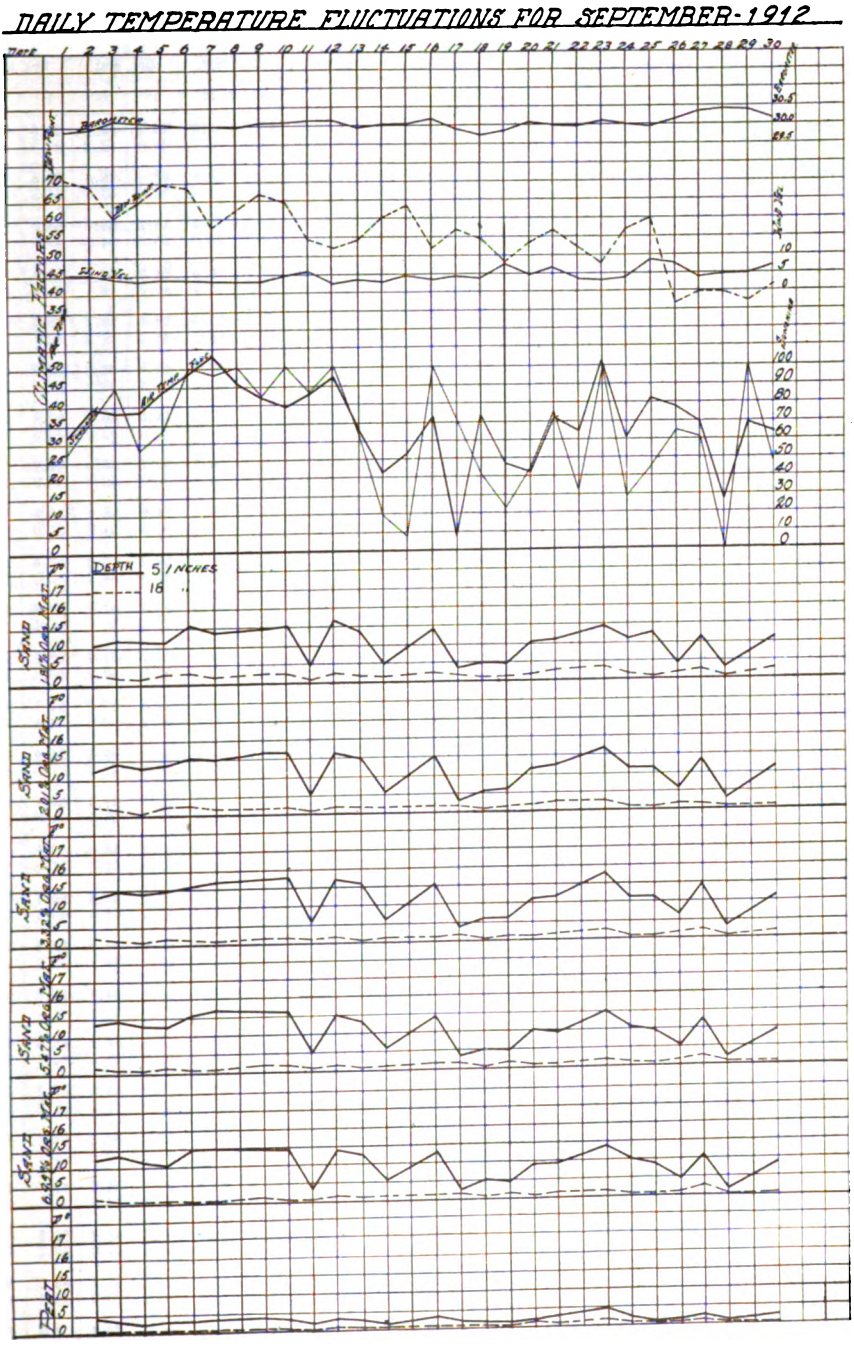


FIG. 46.

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TABLE 65.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, OCTOBER, 1912.

| Date—Maximum, minimum. | Peat. | | 6.96% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.01% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 54.3 | 57.5 | 60.4 | 54.6 | 60.6 | 54.9 | 60.2 | 55.3 | 60.3 | 55.2 | 58.0 | 54.8 |
| 1 Min | 50.4 | 56.6 | 45.6 | 54.3 | 45.0 | 53.6 | 44.3 | 53.7 | 44.8 | 53.2 | 44.3 | 51.9 |
| 2 Max | 53.6 | 56.3 | 61.1 | 55.3 | 61.3 | 54.8 | 62.0 | 55.0 | 62.1 | 55.4 | 60.4 | 55.1 |
| 2 Min | 50.5 | 56.2 | 45.8 | 54.7 | 45.3 | 54.2 | 44.0 | 54.2 | 44.6 | 53.7 | 44.3 | 52.3 |
| 3 Max | 52.7 | 56.7 | 54.8 | 55.8 | 54.8 | 55.6 | 54.0 | 55.8 | 54.8 | 55.4 | 54.0 | 54.6 |
| 3 Min | 51.8 | 56.0 | 50.0 | 55.3 | 49.9 | 55.0 | 50.2 | 55.0 | 50.3 | 54.6 | 49.6 | 53.7 |
| 4 Max | 57.0 | 55.9 | 61.9 | 55.8 | 62.2 | 55.5 | 62.7 | 56.8 | 61.0 | 56.9 | 60.4 | 56.6 |
| 4 Min | 52.8 | 55.5 | 50.0 | 55.0 | 49.7 | 55.0 | 49.2 | 55.1 | 49.3 | 54.7 | 48.9 | 53.8 |
| 5 Max | 57.2 | 56.0 | 64.3 | 56.5 | 64.7 | 56.9 | 65.8 | 57.4 | 64.9 | 56.2 | 63.4 | 56.1 |
| 5 Min | 53.3 | 55.7 | 48.8 | 55.9 | 47.3 | 55.7 | 47.8 | 55.3 | 47.2 | 54.5 | 47.7 | 54.5 |
| 7 Max | 56.8 | 56.6 | 62.2 | 59.3 | 61.0 | 58.4 | 61.7 | 60.0 | 61.5 | 60.0 | 58.9 | 59.0 |
| 7 Min | 57.5 | 56.0 | 57.9 | 58.4 | 57.4 | 58.6 | 56.8 | 58.9 | 57.4 | 58.9 | 57.3 | 58.4 |
| 8 Max | 53.4 | 56.7 | 53.4 | 57.4 | 53.8 | 57.5 | 54.4 | 57.0 | 54.0 | 56.2 | 52.1 | 54.9 |
| 8 Min | 52.2 | 56.4 | 47.0 | 56.3 | 45.9 | 56.4 | 44.8 | 54.5 | 45.0 | 53.8 | 44.4 | 52.9 |
| 9 Max | 53.8 | 55.6 | 56.3 | 54.2 | 56.7 | 54.1 | 56.4 | 54.2 | 56.2 | 54.0 | 55.2 | 53.6 |
| 9 Min | 50.8 | 55.2 | 49.3 | 53.8 | 49.2 | 53.0 | 49.0 | 53.2 | 48.7 | 52.9 | 48.0 | 51.8 |
| 10 Max | 54.6 | 55.8 | 54.7 | 55.4 | 54.8 | 55.3 | 54.9 | 55.4 | 54.5 | 55.1 | 53.9 | 54.5 |
| 10 Min | 53.8 | 55.5 | 53.2 | 55.0 | 52.8 | 54.9 | 52.7 | 54.8 | 52.8 | 54.6 | 51.9 | 54.0 |
| 11 Max | 57.1 | 55.7 | 60.1 | 55.3 | 59.9 | 55.8 | 59.8 | 56.3 | 59.5 | 56.0 | 56.8 | 56.2 |
| 11 Min | 54.5 | 55.4 | 54.1 | 54.8 | 53.9 | 54.5 | 53.4 | 55.0 | 53.8 | 54.8 | 52.0 | 54.2 |
| 12 Max | 58.2 | 56.0 | 56.7 | 57.0 | 56.1 | 57.3 | 55.0 | 57.4 | 55.1 | 57.2 | 54.8 | 56.8 |
| 12 Min | 55.6 | 55.4 | 54.2 | 56.5 | 53.4 | 55.8 | 52.8 | 55.7 | 52.5 | 55.7 | 51.7 | 55.1 |
| 14 Max | 48.6 | 56.1 | 50.8 | 53.1 | 52.4 | 52.9 | 54.0 | 52.4 | 53.7 | 51.6 | 52.9 | 50.7 |
| 14 Min | 48.5 | 53.4 | 50.0 | 50.6 | 51.1 | 50.4 | 50.7 | 51.0 | 51.0 | 50.9 | 50.8 | 50.5 |
| 15 Max | 50.4 | 54.0 | 51.6 | 52.1 | 52.8 | 51.8 | 54.0 | 52.1 | 53.3 | 51.6 | 51.7 | 50.6 |
| 15 Min | 47.4 | 53.8 | 43.5 | 51.7 | 43.5 | 50.5 | 42.5 | 50.8 | 42.7 | 50.6 | 42.4 | 49.5 |
| 16 Max | 47.9 | 53.2 | 53.8 | 51.6 | 53.4 | 51.1 | 52.9 | 50.8 | 53.1 | 50.7 | 51.4 | 49.6 |
| 16 Min | 44.9 | 52.4 | 40.0 | 50.1 | 39.5 | 49.5 | 37.6 | 49.0 | 37.9 | 48.6 | 37.2 | 47.1 |
| 17 Max | 49.4 | 52.3 | 55.9 | 50.0 | 56.1 | 51.3 | 58.4 | 51.8 | 55.7 | 51.5 | 54.7 | 51.1 |
| 17 Min | 45.9 | 52.1 | 42.5 | 50.3 | 43.5 | 50.1 | 41.9 | 50.0 | 42.1 | 49.5 | 41.3 | 48.0 |
| 18 Max | 52.4 | 51.9 | 57.4 | 52.0 | 58.0 | 53.2 | 59.8 | 53.9 | 58.6 | 54.1 | 57.4 | 53.6 |
| 18 Min | 49.5 | 51.0 | 51.3 | 51.3 | 51.6 | 51.5 | 52.5 | 51.8 | 51.5 | 51.6 | 51.0 | 51.0 |
| 19 Max | 51.8 | 52.1 | 50.6 | 52.7 | 50.5 | 53.0 | 51.6 | 53.9 | 51.8 | 53.3 | 50.7 | 52.9 |
| 19 Min | 48.9 | 51.2 | 47.5 | 50.4 | 47.0 | 51.1 | 45.0 | 51.0 | 45.4 | 51.0 | 45.1 | 50.3 |
| 21 Max | 50.9 | 52.9 | 56.7 | 51.8 | 57.3 | 51.3 | 57.4 | 51.9 | 56.9 | 51.0 | 56.4 | 51.4 |
| 21 Min | 47.5 | 52.4 | 44.6 | 50.6 | 44.0 | 50.5 | 42.9 | 50.2 | 42.9 | 49.7 | 42.4 | 48.6 |
| 22 Max | 54.0 | 52.1 | 54.2 | 50.7 | 57.0 | 54.4 | 57.4 | 54.8 | 57.4 | 54.7 | 56.8 | 54.5 |
| 22 Min | 51.7 | 51.3 | 52.1 | 54.0 | 53.4 | 52.5 | 52.0 | 53.4 | 52.1 | 52.7 | 51.7 | 52.3 |
| 23 Max | 49.2 | 52.3 | 45.6 | 51.5 | 44.3 | 51.1 | 43.9 | 51.0 | 43.0 | 50.2 | 43.5 | 49.9 |
| 23 Min | 47.4 | 50.4 | 44.6 | 50.3 | 43.9 | 49.2 | 42.4 | 49.0 | 42.8 | 48.8 | 42.7 | 47.7 |
| 24 Max | 48.2 | 52.6 | 47.9 | 50.3 | 46.9 | 49.6 | 47.2 | 49.4 | 46.5 | 48.3 | 45.7 | 47.3 |
| 24 Min | 45.3 | 52.2 | 39.5 | 49.3 | 38.2 | 48.9 | 36.7 | 48.3 | 37.0 | 47.9 | 37.0 | 46.0 |
| 25 Max | 46.5 | 51.8 | 49.8 | 48.9 | 49.9 | 48.1 | 50.0 | 48.1 | 50.8 | 48.1 | 50.9 | 47.7 |
| 25 Min | 44.7 | 51.3 | 38.3 | 48.1 | 37.3 | 47.2 | 36.1 | 46.9 | 36.5 | 46.3 | 36.3 | 45.0 |
| 26 Max | 46.7 | 51.0 | 50.0 | 48.8 | 49.8 | 48.6 | 51.7 | 48.4 | 51.1 | 48.5 | 49.4 | 47.8 |
| 26 Min | 44.2 | 50.5 | 39.6 | 48.2 | 38.8 | 47.6 | 37.7 | 47.4 | 37.9 | 46.9 | 37.7 | 46.0 |
| 28 Max | 47.9 | 49.6 | 53.8 | 48.9 | 53.5 | 48.9 | 53.4 | 49.3 | 53.6 | 49.4 | 52.5 | 49.0 |
| 28 Min | 44.2 | 49.0 | 42.6 | 47.9 | 42.0 | 47.5 | 41.3 | 47.4 | 41.8 | 47.0 | 41.2 | 45.9 |
| 29 Max | 49.0 | 49.8 | 53.2 | 50.0 | 53.5 | 50.1 | 54.9 | 50.7 | 54.8 | 50.7 | 53.0 | 50.4 |
| 29 Min | 47.2 | 49.4 | 45.4 | 49.7 | 45.2 | 49.5 | 45.0 | 49.7 | 45.3 | 49.5 | 45.1 | 48.8 |
| 30 Max | 48.5 | 49.6 | 44.9 | 49.9 | 44.4 | 49.9 | 44.0 | 49.8 | 44.0 | 49.4 | 42.9 | 48.7 |
| 30 Min | 46.3 | 49.3 | 44.2 | 49.1 | 43.8 | 48.9 | 42.6 | 48.9 | 42.8 | 48.3 | 42.4 | 47.5 |
| 31 Max | 44.9 | 49.6 | 49.4 | 48.0 | 49.3 | 47.6 | 39.6 | 47.4 | 39.6 | 48.6 | 38.9 | 44.8 |
| 31 Min | 42.3 | 49.4 | 38.3 | 46.8 | 37.8 | 46.1 | 36.1 | 45.8 | 35.9 | 45.0 | 35.2 | 43.5 |
| Monthly range | 2.41 | 0.60 | 7.51 | 0.97 | 7.60 | 1.18 | 6.19 | 1.53 | 6.78 | 1.63 | 6.14 | 2.04 |

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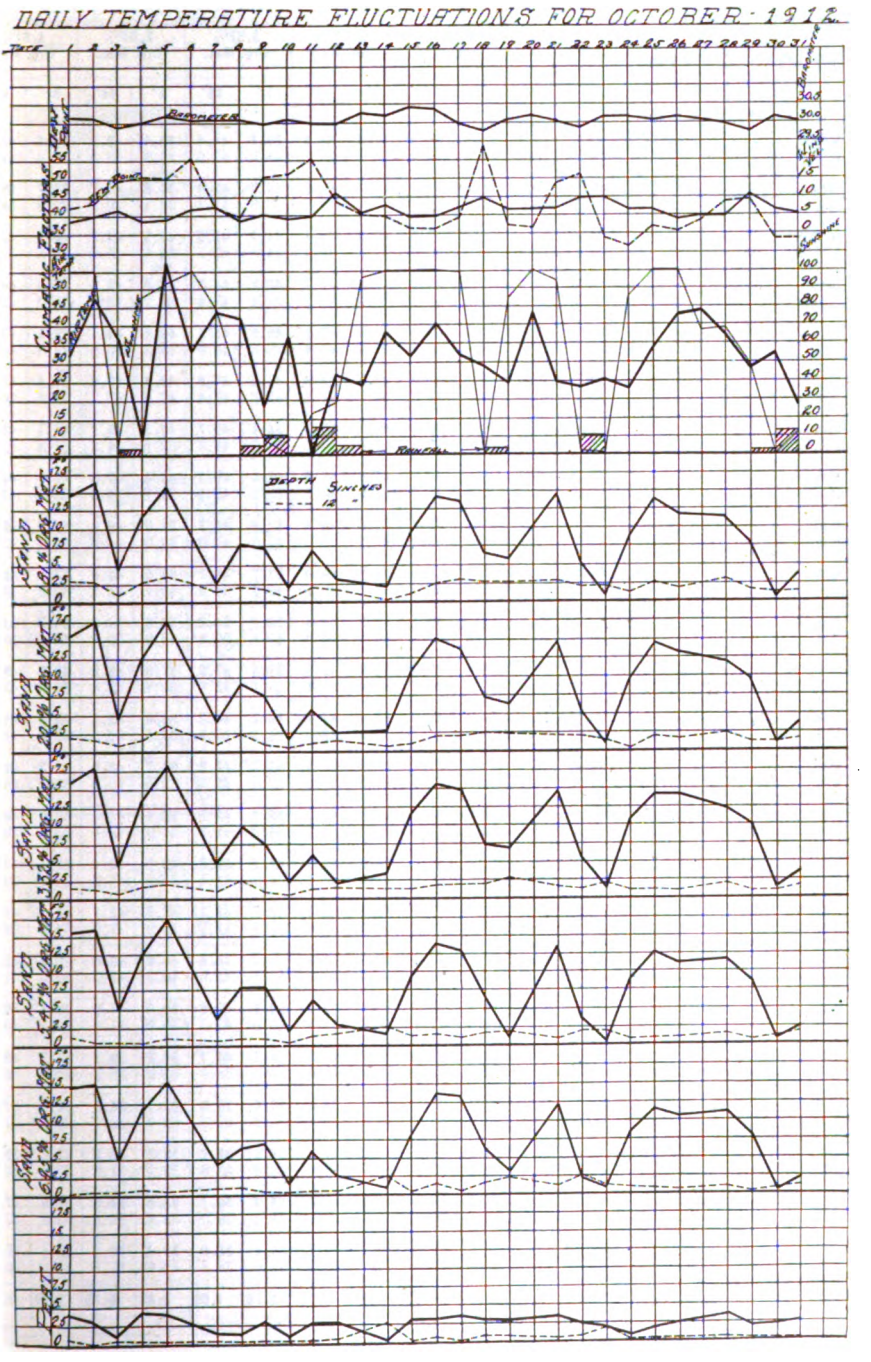


FIG. 47.

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TABLE 66.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, NOVEMBER, 1912.

| Date—Maximum, minimum. | Peat. | | 6.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.01% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 41.0 | 49.1 | 37.1 | 45.8 | 36.2 | 44.8 | 35.3 | 44.4 | 35.4 | 43.9 | 34.8 | 42.2 |
| 1 Min | 39.5 | 48.6 | 35.9 | 44.4 | 35.4 | 43.7 | 34.9 | 43.0 | 34.9 | 42.5 | 34.4 | 41.1 |
| 2 Max | 38.5 | 47.9 | 35.8 | 43.1 | 35.1 | 42.8 | 34.3 | 42.4 | 34.6 | 41.7 | 33.7 | 39.9 |
| 2 Min | 38 2 | 47.1 | 35.1 | 42.7 | 34.7 | 42.2 | 33.6 | 41.8 | 33.4 | 40.9 | 32.9 | 39.2 |
| 4 Max | 37.0 | 45.0 | 40.4 | 42.5 | 40.9 | 42.1 | 41.1 | 42.0 | 41.5 | 41.7 | 40.9 | 40.9 |
| 4 Min | 36.8 | 44.5 | 35.9 | 42.3 | 35.3 | 42.0 | 34.9 | 41.7 | 34.8 | 40.8 | 33.8 | 39.3 |
| 5 Max | 41.8 | 44.6 | 47.2 | 43.9 | 47.9 | 44.1 | 48.8 | 44.5 | 48.8 | 44.3 | 47.9 | 44.2 |
| 5 Min | 39.1 | 43.9 | 39.9 | 43.4 | 39.8 | 43.3 | 39.4 | 43.4 | 39.2 | 42.9 | 38.9 | 42.2 |
| 6 Max | 47.1 | 44.8 | 49.5 | 47.1 | 49.9 | 47.4 | 49.5 | 48.1 | 49.4 | 48.1 | 49.1 | 47.9 |
| 6 Min | 44.8 | 44.2 | 47.9 | 45.9 | 48 3 | 46.4 | 48.3 | 46.9 | 48.3 | 46.8 | 47.8 | 46.6 |
| 7 Max | 46.3 | 45.8 | 46.8 | 47.8 | 47.0 | 47.9 | 47.0 | 47.9 | 46.9 | 47.6 | 45.4 | 47.6 |
| 7 Min | 45.0 | 45.2 | 44.0 | 47.3 | 43.7 | 47.2 | 42.2 | 47.4 | 42.5 | 47.2 | 41.8 | 46.4 |
| 8 Max | 43.3 | 46.2 | 44.2 | 46.3 | 44.1 | 45.7 | 44.4 | 45.7 | 44.3 | 45.7 | 43.1 | 45.9 |
| 8 Min | 42.0 | 45.9 | 39.4 | 45.7 | 38.6 | 45.3 | 38.0 | 44.8 | 38.1 | 44.2 | 37.3 | 43 0 |
| 9 Max | 42.7 | 46.4 | 43.0 | 45.8 | 43.0 | 45.7 | 43.8 | 45.3 | 43.4 | 45.0 | 42.4 | 44.2 |
| 9 Min | 42.2 | 46.0 | 40.0 | 45.2 | 39.9 | 45.1 | 39.2 | 45.1 | 39.1 | 44.8 | 38.4 | 43.8 |
| 10 Max | 45.2 | 45.7 | 51.3 | 45.7 | 51.8 | 46.1 | 52.8 | 46.7 | 52.5 | 46.8 | 51.8 | 46.6 |
| 10 Min | 42.7 | 45.1 | 42.5 | 45.0 | 41.8 | 45.0 | 42.0 | 44.9 | 42.0 | 44.6 | 41.4 | 43.0 |
| 12 Max | 49.5 | 46.2 | 53.1 | 48.9 | 53.2 | 48.9 | 53.7 | 49.7 | 53.5 | 49.6 | 52.8 | 49.9 |
| 12 Min | 47.5 | 45.8 | 49.7 | 48.0 | 49.7 | 48.1 | 49.9 | 48.4 | 49.7 | 48.3 | 49.2 | 48 1 |
| 13 Max | 51.0 | 48.3 | 52.3 | 50.7 | 52.3 | 51.0 | 52.2 | 51.2 | 52.3 | 51.3 | 51.7 | 51.1 |
| 13 Min | 50.1 | 46.9 | 47.4 | 49.7 | 46.3 | 49.9 | 45.1 | 50.4 | 45.0 | 50.3 | 44.4 | 50.0 |
| 14 Max | 44.9 | 48.5 | 39.6 | 48.0 | 36.9 | 47.8 | 37.5 | 47.3 | 37.8 | 48.8 | 37.0 | 45.4 |
| 14 Min | 42.9 | 48.0 | 38.0 | 46.7 | 37.4 | 46.1 | 36.4 | 45.8 | 36.4 | 45.8 | 35.6 | 43.8 |
| 15 Max | 41.2 | 48.1 | 38.4 | 45.0 | 37.4 | 44.4 | 36.7 | 44.2 | 36.4 | 43.3 | 35.9 | 41.8 |
| 15 Main | 40.0 | 47.8 | 35.9 | 44.2 | 35.4 | 43.8 | 34.1 | 43.4 | 34.1 | 42.5 | 32 9 | 41.2 |
| 16 Max | 38.9 | 47.1 | 35.8 | 43.7 | 35.0 | 42.9 | 33.7 | 42.8 | 33.7 | 42.0 | 32.2 | 40.2 |
| 16 Min | 37.8 | 45.8 | 34.2 | 42.2 | 33.5 | 41.6 | 32.8 | 41.3 | 32.5 | 40.3 | 31.2 | 38.7 |
| 17 Max | 37.8 | 43.8 | 39.9 | 42.1 | 39.9 | 42.0 | 39.1 | 42.0 | 39.4 | 41.4 | 38.6 | 40.0 |
| 17 Min | 37.3 | 43.0 | 36.1 | 41.9 | 35.7 | 41.6 | 34.2 | 41.3 | 34.0 | 40.4 | 33.0 | 39.0 |
| 19 Max | 39.0 | 43.4 | 42.6 | 42.2 | 42.8 | 42.0 | 42.7 | 42.6 | 42.7 | 42.1 | 42.1 | 41.8 |
| 19 Min | 37.6 | 43 2 | 36.4 | 41.9 | 36.2 | 41.7 | 35.0 | 41.5 | 34.9 | 41.0 | 34.1 | 39.7 |
| 20 Max | 39.1 | 43.1 | 42.5 | 42.6 | 42.7 | 42.4 | 42.7 | 42.3 | 42.8 | 42.1 | 42.2 | 41.8 |
| 20 Min | 38.1 | 43.0 | 36.5 | 42.2 | 36.2 | 42.0 | 36.4 | 41.7 | 35.9 | 41.0 | 34.0 | 39.7 |
| 21 Max | 40.5 | 42.5 | 43.3 | 42.8 | 44.5 | 42.8 | 45.6 | 43.2 | 45.8 | 43.0 | 45.0 | 42.5 |
| 21 Min | 39.6 | 42.0 | 40.5 | 42.4 | 40.8 | 42.2 | 40.3 | 42.6 | 40.5 | 42.3 | 40.0 | 41.9 |
| 22 Max | 39.3 | 43.0 | 39.3 | 43.0 | 39.4 | 42.9 | 39.9 | 42.6 | 39.8 | 41.9 | 39.3 | 46.5 |
| 22 Min | 38.8 | 42.8 | 36.3 | 42.8 | 36.0 | 42.6 | 35.6 | 42.3 | 35.6 | 41.4 | 34.6 | 40.0 |
| 25 Max | 37.0 | 42.5 | 35.2 | 40.8 | 34.9 | 40.5 | 34.2 | 40.1 | 34.2 | 39.3 | 33.2 | 38.3 |
| 25 Min | 36.7 | 42.5 | 34.0 | 40.0 | 33.9 | 40.0 | 33.0 | 38.7 | 32.9 | 38.2 | 32.0 | 36.8 |
| 26 Max | 36.1 | 41.9 | 34.1 | 39.5 | 34.1 | 39.3 | 33.4 | 39.0 | 33.1 | 38.3 | 32.0 | 37.3 |
| 26 Min | 36.0 | 41.6 | 34.0 | 39.4 | 34.0 | 39.2 | 33.2 | 38.9 | 32.9 | 38.1 | 32.0 | 37.1 |
| 27 Max | 35.8 | 41.4 | 34.2 | 39.2 | 34.2 | 39.1 | 34.0 | 38.7 | 33.2 | 38.2 | 32.2 | 38.8 |
| 27 Min | 35.6 | 41.3 | 34.2 | 39.0 | 34.0 | 39.0 | 33.6 | 38.6 | 33.1 | 37.9 | 32.2 | 36.8 |
| 29 Max | 36.1 | 41.8 | 34.8 | 39.6 | 34.6 | 39.2 | 34.0 | 39.1 | 33.8 | 38.5 | 33.0 | 37.3 |
| 29 Min | 35.9 | 41.5 | 34.7 | 39.4 | 34.5 | 39.1 | 34.0 | 39.0 | 33.8 | 38.3 | 32.9 | 37.3 |
| 30 Max | 35.8 | 41.2 | 34.5 | 39.3 | 34.2 | 39.1 | 33.4 | 38.9 | 33.4 | 38.3 | 32.4 | 37.2 |
| 30 Min | 35.2 | 40.7 | 34.0 | 38.8 | 33.5 | 38.5 | 33.0 | 38.3 | 32.8 | 37.8 | 31.6 | 36.4 |
| Monthly range | 1.06 | 0.50 | 3.01 | 0.41 | 3.31 | 0.99 | 3.78 | 1.09 | 3.83 | 0.95 | 3.81 | 1.25 |

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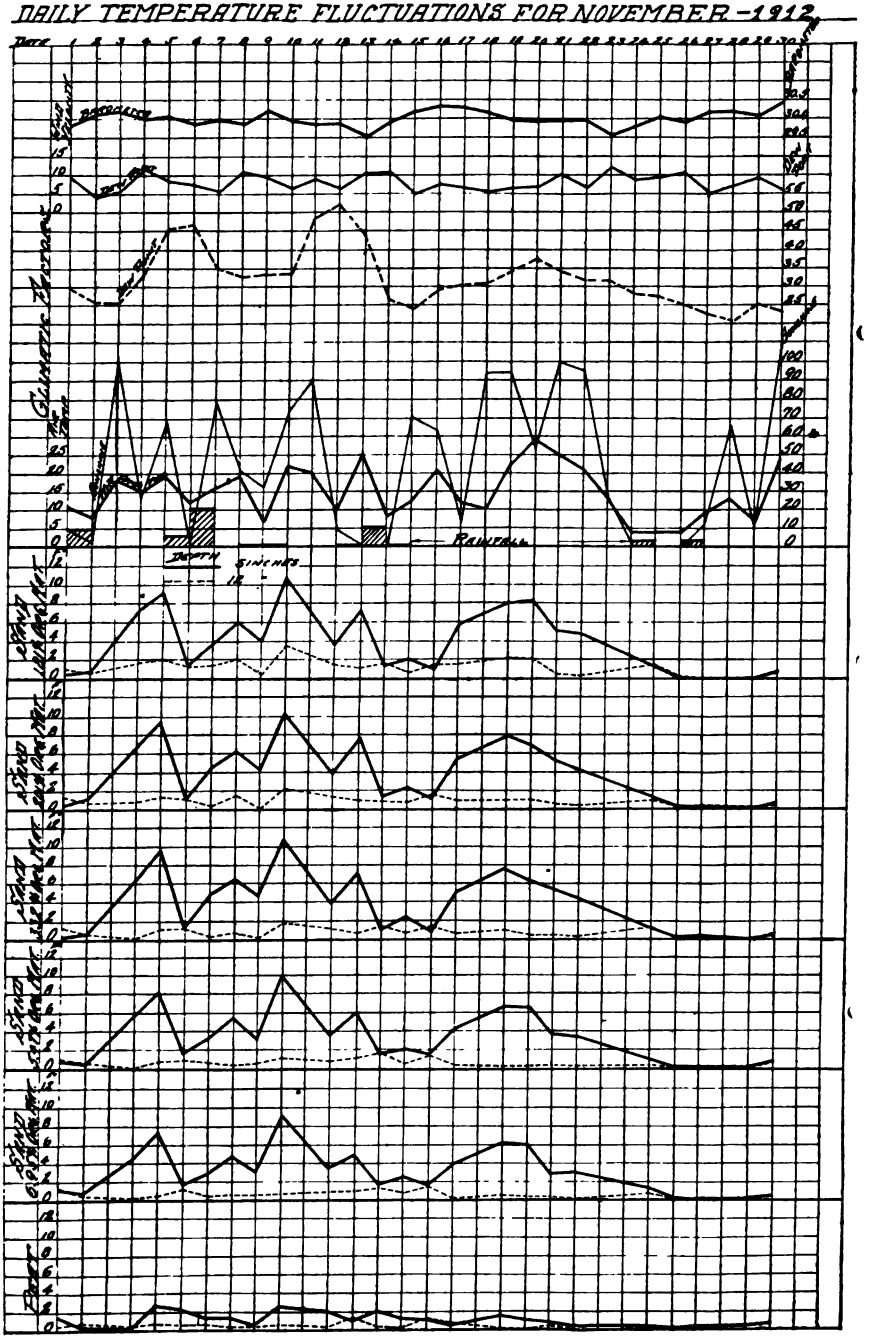


FIG. 48.



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TABLE 67.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, DECEMBER, 1912.

| Date—Maximum, minimum. | Peat. | | 6.95% Org. Mat. | | 5.47% Org. Mat. | | 3.32% Org. Mat. | | 2.61% Org. Mat. | | 1.81% Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 2 Max | 40.5 | 40.3 | 44.8 | 42.2 | 45.9 | 42.6 | 47.1 | 43.0 | 47.0 | 43.6 | 48.4 | 42.0 |
| 2 Min | 38.4 | 40.1 | 41.1 | 40.2 | 40.4 | 40.6 | 38.7 | 41.7 | 38.9 | 41.6 | 38.1 | 41.4 |
| 3 Max | 38.8 | 41.0 | 37.0 | 41.9 | 38.0 | 41.8 | 35.5 | 41.4 | 35.5 | 40.8 | 34.0 | 39.8 |
| 3 Min | 37.5 | 40.8 | 36.2 | 41.1 | 36.0 | 40.6 | 35.0 | 40.3 | 35.0 | 39.6 | 34.0 | 38.4 |
| 4 Max | 37.5 | 40.9 | 39.0 | 40.1 | 39.3 | 39.9 | 40.2 | 40.1 | 40.0 | 39.9 | 39.1 | 39.4 |
| 4 Min | 36.6 | 40.2 | 37.0 | 39.9 | 37.0 | 39.8 | 36.8 | 39.8 | 36.6 | 39.4 | 36.0 | 38.4 |
| 5 Max | 37.8 | 40.8 | 42.7 | 40.2 | 43.8 | 40.3 | 44.4 | 40.5 | 44.3 | 40.3 | 43.6 | 39.7 |
| 5 Min | 36.5 | 40.2 | 35.5 | 39.9 | 35.3 | 39.7 | 35.0 | 39.5 | 34.8 | 39.0 | 33.5 | 38.0 |
| 6 Max | 41.6 | 41.0 | 43.0 | 42.8 | 42.7 | 42.8 | 41.4 | 43.2 | 41.5 | 43.2 | 40.0 | 42.1 |
| 6 Min | 39.6 | 40.9 | 37.7 | 42.1 | 37.0 | 42.0 | 36.0 | 41.9 | 35.8 | 41.5 | 34.9 | 40.4 |
| 7 Max | 37.7 | 41.3 | 35.5 | 40.9 | 35.0 | 40.0 | 33.9 | 40.2 | 33.8 | 39.5 | 32.8 | 38.4 |
| 7 Min | 36.9 | 40.9 | 34.9 | 40.0 | 34.3 | 39.6 | 33.4 | 39.4 | 33.3 | 38.7 | 32.5 | 37.5 |
| 9 Max | 35.0 | 40.6 | 33.1 | 38.5 | 32.9 | 38.3 | 31.7 | 38.1 | 31.4 | 37.2 | 30.3 | 36.8 |
| 9 Min | 34.6 | 40.3 | 33.1 | 38.2 | 32.6 | 37.9 | 31.2 | 37.7 | 30.8 | 36.9 | 29.5 | 35.6 |
| 10 Max | 34.4 | 40.0 | 32.8 | 37.7 | 32.4 | 37.4 | 32.0 | 37.2 | 31.8 | 36.4 | 31.1 | 35.3 |
| 10 Min | 33.7 | 39.2 | 31.9 | 37.1 | 31.5 | 36.8 | 30.7 | 36.7 | 30.4 | 36.2 | 29.3 | 34.9 |
| 11 Max | 34.5 | 39.8 | 33.2 | 37.9 | 32.9 | 37.7 | 32.1 | 37.6 | 31.0 | 36.6 | 31.1 | 35.6 |
| 11 Min | 33.4 | 38.9 | 32.2 | 37.1 | 31.6 | 36.7 | 30.4 | 36.6 | 30.4 | 35.9 | 29.2 | 34.8 |
| 12 Max | 33.5 | 38.9 | 31.3 | 37.1 | 29.4 | 36.5 | 27.3 | 36.4 | 26.9 | 35.0 | 25.7 | 34.3 |
| 12 Min | 33.1 | 38.4 | 30.6 | 36.4 | 29.0 | 36.3 | 26.4 | 35.9 | 26.7 | 35.0 | 24.4 | 33.6 |
| 13 Max | 32.8 | 38.4 | 30.8 | 36.2 | 30.7 | 35.9 | 30.5 | 35.5 | 30.6 | 34.6 | 29.8 | 33.3 |
| 13 Min | 32.6 | 37.9 | 29.5 | 35.8 | 28.0 | 35.5 | 26.3 | 35.2 | 26.1 | 34.3 | 24.9 | 33.1 |
| 14 Max | 32.8 | 37.8 | 31.2 | 35.9 | 31.2 | 35.7 | 31.3 | 35.4 | 31.4 | 34.7 | 30.8 | 33.2 |
| 14 Min | 31.6 | 36.7 | 29.5 | 34.9 | 28.4 | 34.6 | 26.6 | 34.3 | 26.5 | 33.5 | 25.2 | 31.9 |
| 16 Max | 32.3 | 36.8 | 31.4 | 35.2 | 31.5 | 35.0 | 31.4 | 35.0 | 31.3 | 34.4 | 31.4 | 33.2 |
| 16 Min | 32.0 | 36.7 | 31.3 | 35.0 | 31.3 | 34.8 | 31.3 | 34.9 | 31.2 | 34.3 | 30.5 | 33.1 |
| 17 Max | 32.5 | 36.9 | 31.7 | 35.5 | 31.9 | 35.2 | 32.1 | 35.3 | 32.8 | 35.0 | 34.1 | 34.3 |
| 17 Min | 32.2 | 36.7 | 31.3 | 35.2 | 31.6 | 35.0 | 31.6 | 35.0 | 31.4 | 34.8 | 30.7 | 33.4 |
| 18 Max | 33.1 | 37.4 | 32.4 | 36.2 | 32.7 | 35.9 | 32.7 | 36.0 | 33.6 | 35.0 | 32.8 | 35.0 |
| 18 Min | 32.9 | 37.2 | 32.2 | 35.9 | 32.4 | 35.7 | 32.4 | 35.9 | 32.8 | 35.7 | 32.1 | 34.9 |
| 19 Max | 33.2 | 37.3 | 32.4 | 36.4 | 32.8 | 36.2 | 33.0 | 36.4 | 33.0 | 35.9 | 32.0 | 35.1 |
| 19 Min | 33.0 | 37.0 | 32.2 | 35.9 | 32.3 | 35.9 | 32.9 | 36.1 | 32.9 | 35.8 | 32.0 | 34.9 |
| 20 Max | 33.1 | 37.3 | 32.4 | 36.1 | 32.8 | 36.0 | 32.8 | 36.2 | 32.7 | 35.0 | 31.5 | 34.8 |
| 20 Min | 32.9 | 36.9 | 32.1 | 35.8 | 32.2 | 35.6 | 32.6 | 35.9 | 32.3 | 35.5 | 31.2 | 34.5 |
| 21 Max | 33.1 | 37.1 | 32.7 | 36.0 | 32.9 | 36.1 | 32.9 | 36.3 | 32.8 | 35.8 | 31.6 | 34.8 |
| 21 Min | 33.0 | 36.9 | 32.5 | 35.9 | 32.7 | 35.9 | 32.7 | 36.2 | 32.7 | 35.7 | 31.6 | 34.6 |
| 23 Max | 32.9 | 36.8 | 32.4 | 35.9 | 31.9 | 35.9 | 31.6 | 35.9 | 30.9 | 35.6 | 29.1 | 34.3 |
| 23 Min | 31.9 | 35.9 | 31.3 | 35.0 | 31.2 | 35.0 | 31.1 | 35.1 | 30.5 | 34.5 | 29.2 | 33.2 |
| 24 Max | 32.1 | 36.0 | 31.3 | 35.2 | 31.4 | 35.0 | 31.2 | 35.0 | 31.1 | 34.7 | 30.2 | 33.4 |
| 24 Min | 31.9 | 35.8 | 31.1 | 35.0 | 31.1 | 34.9 | 31.0 | 34.9 | 30.7 | 34.1 | 29.7 | 33.0 |
| 26 Max | 32.7 | 36.4 | 31.8 | 35.6 | 31.9 | 35.4 | 31.8 | 35.3 | 31.8 | 35.0 | 30.9 | 33.8 |
| 26 Min | 32.3 | 36.2 | 31.1 | 35.2 | 30.5 | 35.0 | 29.8 | 35.1 | 28.9 | 34.6 | 27.3 | 33.2 |
| 27 Max | 32.9 | 36.6 | 32.4 | 35.9 | 32.7 | 35.8 | 32.3 | 35.9 | 32.2 | 35.2 | 31.4 | 34.2 |
| 27 Min | 32.6 | 36.4 | 32.0 | 35.7 | 31.9 | 35.4 | 32.1 | 35.5 | 32.1 | 35.1 | 30.9 | 34.2 |
| 28 Max | 32.9 | 36.6 | 31.4 | 35.9 | 31.3 | 35.7 | 31.2 | 35.8 | 31.2 | 35.0 | 30.5 | 34.0 |
| 28 Min | 32.1 | 36.0 | 31.3 | 35.0 | 30.4 | 35.0 | 29.8 | 34.9 | 28.1 | 34.1 | 26.1 | 33.1 |
| 30 Max | 33.2 | 36.4 | 32.2 | 35.7 | 32.3 | 35.5 | 32.4 | 35.4 | 32.2 | 35.0 | 31.3 | 33.9 |
| 30 Min | 32.4 | 36.1 | 31.8 | 35.2 | 31.9 | 35.0 | 32.1 | 35.0 | 31.8 | 34.7 | 31.0 | 33.3 |
| 31 Max | 32.2 | 36.0 | 32.0 | 35.1 | 32.0 | 35.0 | 31.9 | 35.0 | 31.8 | 34.7 | 31.1 | 33.6 |
| 31 Min | 31.4 | 35.5 | 31.2 | 34.4 | 31.4 | 34.2 | 31.2 | 34.3 | 31.2 | 33.9 | 30.4 | 32.9 |
| Monthly range | 9.70 | 6.43 | 1.24 | 6.56 | 1.55 | 6.59 | 1.91 | 6.57 | 2.66 | 6.63 | 2.43 | 6.74 |

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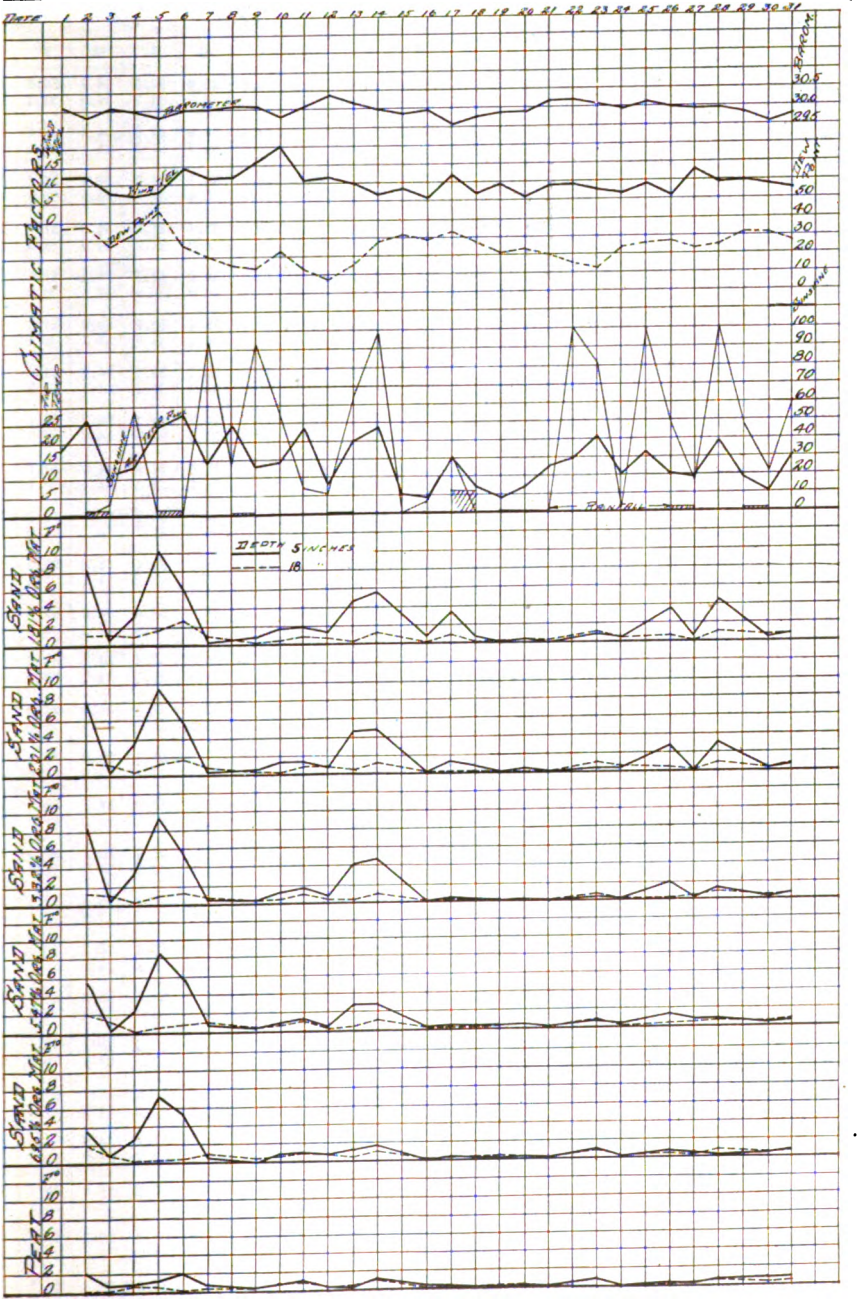


FIG. 49.

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TABLE 68.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, JANUARY, 1913.

| Date—Maximum, minimum. | | Peat. | | 6.86% Peat. | | 5.47% Peat. | | 3.32% Peat. | | 2.01% Peat. | | 1.81% Peat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 | Max. | 31.9 | 35.7 | 31.7 | 34.9 | 31.9 | 34.9 | 31.8 | 35.0 | 31.5 | 34.3 | 30.8 | 33.3 |
| | Min. | 31.7 | 35.6 | 31.2 | 34.6 | 31.6 | 34.5 | 31.3 | 34.6 | 31.2 | 34.0 | 30.3 | 33.1 |
| 2 | Max. | 31.9 | 35.7 | 31.6 | 34.9 | 31.8 | 34.9 | 31.9 | 34.9 | 31.6 | 34.3 | 30.9 | 33.4 |
| | Min. | 31.7 | 35.3 | 31.3 | 34.7 | 31.6 | 34.7 | 31.2 | 34.7 | 31.3 | 34.1 | 30.4 | 33.2 |
| 3 | Max. | 32.6 | 36.0 | 32.1 | 35.3 | 32.3 | 35.3 | 32.2 | 35.5 | 32.2 | 34.9 | 31.1 | 34.0 |
| | Min. | 32.1 | 35.8 | 31 7 | 35.0 | 31.8 | 35.0 | 31.9 | 35.0 | 31.6 | 34.5 | 30.9 | 33.5 |
| 4 | Max. | 32.6 | 36.0 | 32.2 | 35.3 | 32.0 | 35.2 | 32.0 | 35.4 | 31.8 | 34.9 | 31.3 | 34.0 |
| | Min. | 32 2 | 35.8 | 31 9 | 35.0 | 31.9 | 35.0 | 31.8 | 35.0 | 31.6 | 34.8 | 31.0 | 33 7 |
| 6 | Max. | 31.9 | 36.0 | 31.7 | 35.1 | 31.8 | 34.9 | 31.9 | 34.9 | 31.7 | 34.3 | 31.8 | 33.2 |
| | Min. | 31.3 | 35.3 | 31.1 | 34.3 | 31.2 | 34.1 | 31.0 | 34.0 | 30.9 | 32.8 | 29.9 | 32.2 |
| 7 | Max. | 32.9 | 36.5 | 32.2 | 35.6 | 32.1 | 35.7 | 31.9 | 35.8 | 31.9 | 35.0 | 31.0 | 34.1 |
| | Min. | 32.3 | 36.2 | 31.9 | 35.2 | 31.9 | 35.1 | 31.7 | 35.1 | 31.8 | 34.7 | 30.4 | 33.7 |
| 8 | Max. | 32.8 | 36.4 | 32.6 | 35.7 | 32.3 | 35.3 | 32.3 | 35.3 | 32.1 | 34.9 | 31.1 | 34.6 |
| | Min. | 32.8 | 36.4 | 32 6 | 35.7 | 32.3 | 35.3 | 32.3 | 35.3 | 32.1 | 34.9 | 31.1 | 34.0 |
| 9 | Max. | 32.0 | 35.4 | 31.4 | 34.7 | 31.2 | 34.7 | 31.1 | 34.7 | 31.1 | 34.2 | 30.1 | 33.3 |
| | Min. | 31.7 | 35.2 | 31.3 | 34.4 | 31.1 | 34.3 | 31.0 | 34.5 | 30.9 | 34.0 | 29.7 | 33.0 |
| 10 | Max. | 32.3 | 35.9 | 31.8 | 35.1 | 31.5 | 34.9 | 31.4 | 34.9 | 31.3 | 34.8 | 30.7 | 33.7 |
| | Min. | 32.1 | 35.7 | 31.6 | 34 9 | 31.4 | 34.8 | 31.3 | 34.7 | 31.3 | 34.1 | 30.1 | 33.2 |
| 11 | Max. | 32.1 | 35.7 | 32.0 | 34.9 | 32.1 | 34.7 | 32.1 | 34.7 | 31.6 | 34.4 | 31.2 | 33.3 |
| | Min. | 32 0 | 35.6 | 31.9 | 34.7 | 31.9 | 34.5 | 32.0 | 34.5 | 31.7 | 34.1 | 31.0 | 33.2 |
| 13 | Max. | 32.5 | 35.9 | 32.6 | 35.1 | 32.5 | 35.2 | 32.5 | 34.9 | 32.4 | 34.9 | 30.1 | 33.8 |
| | Min. | 32.3 | 35.7 | 32.3 | 34.9 | 32.3 | 35.0 | 32.4 | 34.9 | 32.2 | 34.7 | 29.1 | 33.7 |
| 14 | Max. | 32.6 | 36.0 | 32.8 | 35.2 | 32.5 | 35.1 | 32.4 | 35.1 | 32.4 | 34.8 | 30.6 | 33.8 |
| | Min. | 31.9 | 35.6 | 32.1 | 34.8 | 31.8 | 34.8 | 31.9 | 34.9 | 31.6 | 34.2 | 29.9 | 33.0 |
| 15 | Max. | 32.4 | 36.0 | 32.8 | 35.2 | 32.3 | 35.2 | 32.4 | 35.2 | 32.3 | 34.7 | 31.2 | 33.7 |
| | Min. | 32.0 | 35.6 | 32.1 | 34.8 | 31.8 | 34.9 | 32.0 | 34.9 | 31.4 | 34.3 | 30.1 | 33.2 |
| 16 | Max. | 32.3 | 35.9 | 32.4 | 35.2 | 32.4 | 35.1 | 32.5 | 35.1 | 32.3 | 34.9 | 31.8 | 33.5 |
| | Min. | 32.2 | 35.7 | 32.3 | 35.1 | 32.2 | 34.9 | 32.0 | 34.6 | 31.9 | 33.8 | 31.3 | 33.2 |
| 17 | Max. | 32.3 | 35.9 | 32.4 | 35.3 | 32.5 | 34.9 | 32.4 | 34.8 | 32.7 | 34.9 | 32.6 | 33.8 |
| | Min. | 32.2 | 35.6 | 32.2 | 35.2 | 32.2 | 34.8 | 32.2 | 34.8 | 32.2 | 33.9 | 31.9 | 33.2 |
| 18 | Max. | 32.3 | 35.8 | 32.6 | 35.2 | 32.7 | 34.9 | 32.7 | 34.8 | 32.6 | 34.2 | 31.9 | 33.9 |
| | Min. | 32.0 | 35.4 | 32.1 | 34.9 | 32.1 | 34.5 | 32.0 | 34.7 | 32.1 | 34.1 | 31.9 | 33.7 |
| 20 | Max. | 32.9 | 36.1 | 32.9 | 35.8 | 32.9 | 35.3 | 32.9 | 35.2 | 32.9 | 35.1 | 32.0 | 34.3 |
| | Min. | 32.5 | 35.6 | 32 5 | 35.2 | 32 4 | 35.0 | 32.3 | 34.9 | 32.1 | 34.8 | 31.9 | 34.0 |
| 21 | Max. | 33.0 | 36.3 | 33.1 | 35.8 | 33.1 | 35.7 | 33.2 | 35.8 | 33.1 | 35.4 | 32.9 | 34.9 |
| | Min. | 32.4 | 35.9 | 32.8 | 35.1 | 32.7 | 35.2 | 33.1 | 35.1 | 32.8 | 34.9 | 32.1 | 34.5 |
| 22 | Max. | 32.9 | 36.0 | 33.0 | 35.3 | 33.0 | 35.6 | 33.3 | 35.8 | 32.9 | 35.2 | 32.2 | 34.4 |
| | Min | 32.4 | 35.6 | 32.8 | 35.0 | 32.7 | 35.0 | 33.0 | 35.1 | 32.8 | 34.9 | 31.7 | 34.1 |
| 23 | Max. | 32.9 | 36.0 | 32.9 | 35.4 | 32.9 | 35.5 | 33.2 | 35.7 | 33.0 | 35.2 | 32.0 | 34.4 |
| | Min. | 32.8 | 35.8 | 32.9 | 35.2 | 32.9 | 35.3 | 33.0 | 35.6 | 32.9 | 35.0 | 31.9 | 34.1 |
| 24 | Max. | 32.9 | 35.9 | 33.0 | 35.6 | 33.2 | 35.7 | 33.1 | 35.8 | 33.0 | 35.3 | 32.1 | 34.6 |
| | Min. | 32.4 | 35.4 | 32.7 | 35.1 | 32.9 | 35.1 | 32.9 | 35.2 | 32.7 | 34.9 | 31.8 | 34.0 |
| 25 | Max. | 32.8 | 35.8 | 32.9 | 35.2 | 33.3 | 35.6 | 33.0 | 35.5 | 32.4 | 35.1 | 31.3 | 34.1 |
| | Min. | 32 4 | 35.6 | 32.7 | 35.0 | 33.0 | 35.1 | 32.8 | 35.1 | 32.2 | 34.9 | 30.2 | 33.8 |
| 27 | Max. | 32.6 | 35.7 | 32.8 | 35.0 | 33.1 | 35.2 | 32.9 | 35.2 | 31.7 | 34.9 | 30.9 | 34.0 |
| | Min. | 32.2 | 35.3 | 32.7 | 35.0 | 32.9 | 35.1 | 31.3 | 35.1 | 30.2 | 34.8 | 29.4 | 33.9 |
| 28 | Max. | 32.2 | 35.7 | 32.1 | 35.1 | 32.4 | 35.1 | 28.7 | 35.0 | 28.9 | 34.0 | 28.1 | 33.8 |
| | Min. | 31.5 | 35.1 | 30.1 | 34.9 | 30.9 | 34.9 | 27.9 | 34.8 | 26.8 | 34.1 | 26.9 | 33.2 |
| 29 | Max. | 30.0 | 35.4 | 30.0 | 35.0 | 36.3 | 35.0 | 27.4 | 34.9 | 27.2 | 34.2 | 26.8 | 33.2 |
| | Min. | 30.2 | 35.2 | 25.2 | 34.7 | 25.6 | 34.4 | 22.2 | 34.1 | 21.9 | 33.6 | 20.8 | 32.8 |
| 30 | Max. | 31.3 | 35.2 | 31.8 | 34.2 | 31.9 | 34.3 | 31.8 | 34.1 | 31.8 | 33.4 | 31.3 | 32.8 |
| | Min. | 31.0 | 35.0 | 28.9 | 34.0 | 29.1 | 34.0 | 27.9 | 33.9 | 27.9 | 33.2 | 27.3 | 32.3 |
| 31 | Max. | 32.0 | 35.1 | 31.9 | 34.4 | 32.1 | 34.2 | 32.2 | 33.9 | 32.0 | 33.6 | 31.3 | 32.8 |
| | Min. | 31.8 | 34.9 | 31.7 | 33.9 | 30.2 | 34.1 | 32.0 | 33.8 | 31.9 | 33.3 | 31.1 | 32.3 |
| Monthly range | | 0.30 | 0.30 | 0.62 | 0.31 | 0.64 | 0.32 | 0.60 | 0.32 | 0.78 | 0.36 | 0.92 | 0.36 |

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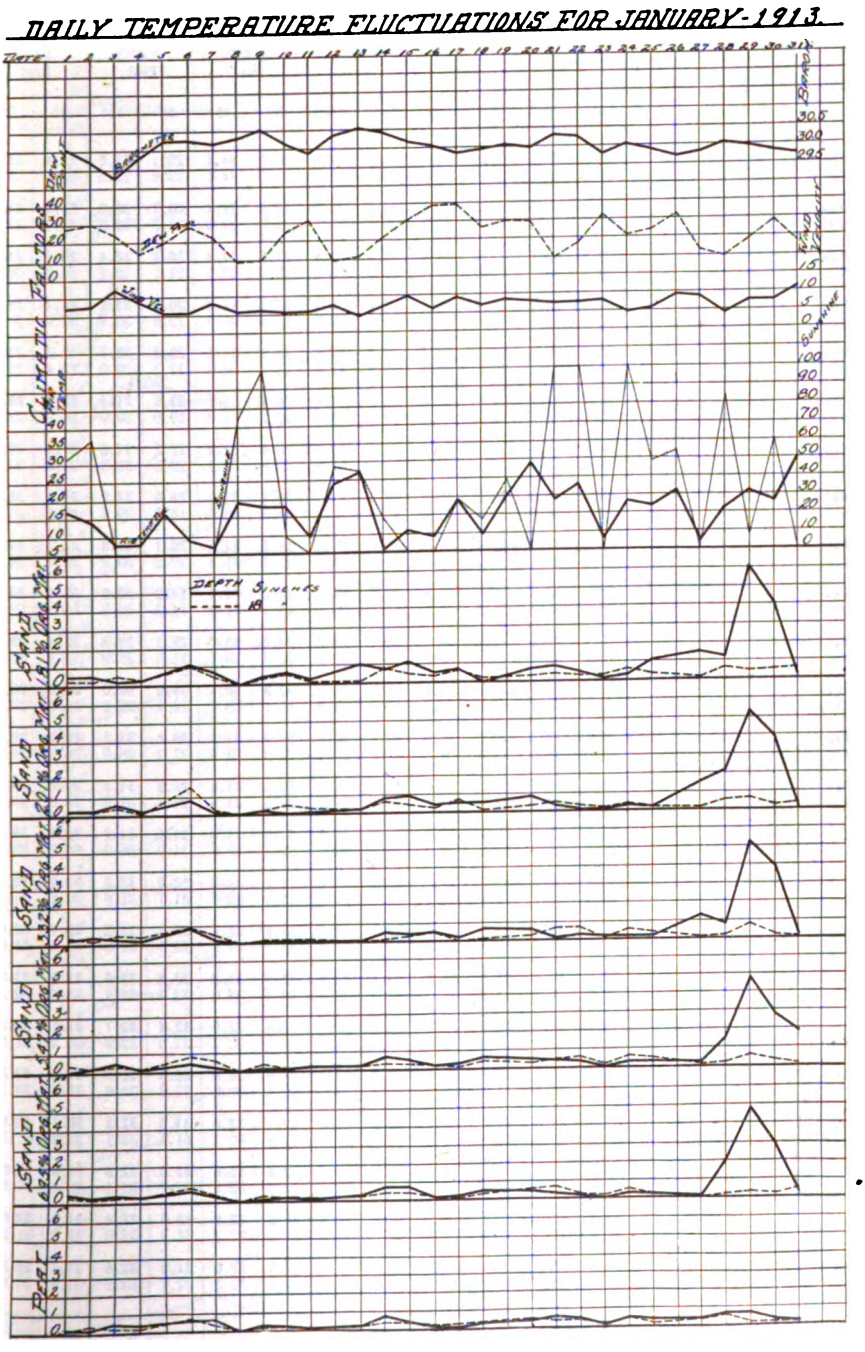


FIG. 50.

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TABLE 69.—EFFECT OF ORGANIC MATTER ON TEMPERATURE OF SOILS. DAILY MAXIMUM AND MINIMUM, FEBRUARY, 1913.

| Date—Maximum, minimum. | Peat. | | 6.95% Peat. | | 5.47% Peat. | | 3.32% Peat. | | 2.01% Peat. | | 1.81% Peat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1 Max | 28.9 | 35.2 | 28.3 | 34.4 | 28.2 | 34.3 | 25.8 | 34.1 | 28.1 | 33.8 | 25.4 | 33.0 |
| 1 Min | 28.3 | 35.0 | 23.3 | 34.2 | 23.3 | 34.2 | 21.7 | 34.1 | 23.8 | 33.5 | 23.8 | 32.8 |
| 3 Max | 30.3 | 34.9 | 29.7 | 33.8 | 30.1 | 33.3 | 29.3 | 33.4 | 28.7 | 32.6 | 27.9 | 31.7 |
| 3 Min | 27.9 | 34.6 | 25.1 | 33.3 | 25.4 | 33.1 | 24.9 | 33.0 | 24.7 | 32.0 | 23.9 | 31.0 |
| 4 Max | 28.7 | 35.0 | 27.0 | 33.8 | 27.9 | 33.6 | 27.6 | 33.4 | 26.2 | 32.4 | 25.1 | 31.1 |
| 4 Min | 26.3 | 34.9 | 22.0 | 33.4 | 22.3 | 33.5 | 20.9 | 33.1 | 21.1 | 32.2 | 21.0 | 30.7 |
| 5 Max | 25.4 | 34.7 | 22.8 | 33.2 | 22.0 | 33.1 | 21.1 | 32.9 | 20.3 | 31.2 | 19.1 | 28.8 |
| 5 Min | 22.1 | 34.3 | 13.8 | 32.9 | 14.2 | 32.1 | 12.9 | 31.9 | 12.9 | 30.7 | 12.9 | 28.0 |
| 6 Max | 25.1 | 34.5 | 24.0 | 33.4 | 22.7 | 32.8 | 29.9 | 31.6 | 20.7 | 30.7 | 19.7 | 27.8 |
| 6 Min | 20.2 | 34.1 | 13.8 | 32.9 | 13.8 | 31.7 | 13.2 | 30.9 | 12.1 | 29.9 | 12.4 | 26.9 |
| 7 Max | 27.7 | 34.2 | 28.9 | 34.0 | 24.2 | 31.9 | 24.1 | 31.7 | 23.5 | 31.1 | 22.7 | 29.4 |
| 7 Min | 25.1 | 34.1 | 21.2 | 33.5 | 21.0 | 31.8 | 20.1 | 31.2 | 19.9 | 30.9 | 19.7 | 28.8 |
| 8 Max | 29.9 | 34.2 | 29.1 | 33.2 | 26.2 | 31.3 | 26.8 | 31.3 | 27.2 | 31.2 | 26.7 | 36.1 |
| 8 Min | 25.5 | 33.3 | 23.1 | 31.8 | 24.0 | 31.1 | 23.8 | 31.1 | 22.8 | 30.8 | 22.2 | 29.6 |
| 10 Max | 28.9 | 33.6 | 30.3 | 32.6 | 29.0 | 31.1 | 29.1 | 31.5 | 29.6 | 31.0 | 27.9 | 38.9 |
| 10 Min | 22.8 | 33.3 | 17.4 | 31.7 | 16.9 | 30.2 | 15.3 | 30.9 | 15.8 | 30.2 | 16.2 | 28.3 |
| 11 Max | 29.3 | 33.9 | 29.0 | 31.3 | 29.0 | 31.2 | 29.2 | 31.5 | 29.1 | 31.3 | 27.2 | 36.7 |
| 11 Min | 29.0 | 32.8 | 28.2 | 31.2 | 27.5 | 31.1 | 25.3 | 31.4 | 26.2 | 30.9 | 25.9 | 30.2 |
| 12 Max | 25.3 | 33.0 | 21.2 | 31.8 | 22.4 | 30.7 | 22.2 | 31.1 | 21.2 | 30.0 | 29.4 | 28.1 |
| 12 Min | 21.7 | 33.1 | 15.9 | 31.2 | 15.5 | 30.2 | 13.1 | 31.0 | 14.2 | 30.3 | 14.9 | 28.3 |
| 13 Max | 26.7 | 33.2 | 28.2 | 30.7 | 24.9 | 29.2 | 23.8 | 36.0 | 23.3 | 29.8 | 22.4 | 28.6 |
| 13 Min | 19.2 | 32.9 | 13.1 | 30.0 | 13.2 | 28.3 | 10.3 | 29.4 | 11.8 | 28.9 | 12.1 | 26.8 |
| 14 Max | 28.6 | 32.9 | 29.8 | 29.8 | 30.0 | 28.3 | 30.9 | 30.1 | 36.0 | 30.9 | 28.9 | 28.2 |
| 14 Min | 22.0 | 32.3 | 16.9 | 28.6 | 17.8 | 27.8 | 16.1 | 28.7 | 16.4 | 28.2 | 16.9 | 27.0 |
| 15 Max | 29.3 | 32.7 | 30.2 | 30.8 | 30.2 | 30.7 | 30.7 | 31.3 | 30.4 | 31.2 | 29.9 | 39.7 |
| 15 Min | 29.0 | 31.8 | 29.3 | 29.8 | 28.8 | 29.2 | 29.0 | 29.8 | 27.2 | 28.9 | 26.9 | 26.9 |
| 17 Max | 30.2 | 32.5 | 30.3 | 31.1 | 30.9 | 31.3 | 30.1 | 31.8 | 29.9 | 31.0 | 29.6 | 30.9 |
| 17 Min | 29.7 | 32.2 | 28.7 | 31.0 | 28.8 | 31.1 | 28.6 | 31.4 | 28.3 | 31.2 | 27.6 | 30.4 |
| 18 Max | 30.9 | 32.4 | 30.8 | 30.9 | 31.0 | 31.0 | 31.9 | 31.6 | 31.2 | 31.3 | 30.4 | 30.8 |
| 18 Min | 27.3 | 32.2 | 24.8 | 30.3 | 25.2 | 30.7 | 24.7 | 30.9 | 24.0 | 30.9 | 23.7 | 29.2 |
| 19 Max | 31.2 | 32.8 | 31.7 | 31.7 | 32.3 | 31.9 | 32.2 | 32.2 | 32.6 | 32.2 | 31.4 | 32.9 |
| 19 Min | 30.9 | 32.1 | 31.4 | 31.1 | 31.7 | 31.4 | 31.8 | 32.0 | 31.7 | 31.9 | 30.8 | 31.4 |
| 20 Max | 31.7 | 32.9 | 32.3 | 31.9 | 32.9 | 32.2 | 34.9 | 32.3 | 33.1 | 32.2 | 32.1 | 32.6 |
| 20 Min | 31.2 | 32.2 | 31.8 | 31.3 | 32.7 | 31.8 | 33.2 | 31.9 | 32.9 | 31.9 | 31.8 | 31.6 |
| 21 Max | 32.3 | 33.1 | 32.6 | 32.3 | 33.1 | 32.9 | 33.6 | 33.2 | 32.8 | 33.6 | 31.9 | 32.9 |
| 21 Min | 31.9 | 33.0 | 32.2 | 32.0 | 32.6 | 32.2 | 32.4 | 32.9 | 32.3 | 32.4 | 31.4 | 32.1 |
| 22 Max | 32.1 | 32.8 | 32.3 | 32.2 | 32.7 | 32.4 | 32.4 | 32.9 | 32.4 | 32.7 | 31.7 | 32.2 |
| 22 Min | 31.8 | 32.6 | 32.0 | 32.0 | 32.3 | 32.2 | 32.1 | 32.7 | 32.0 | 32.3 | 31.2 | 31.8 |
| 24 Max | 32.4 | 33.0 | 32.4 | 32.6 | 32.7 | 32.7 | 32.6 | 32.9 | 32.8 | 32.7 | 31.9 | 32.3 |
| 24 Min | 32.3 | 32.9 | 32.3 | 32.2 | 32.6 | 32.6 | 32.4 | 32.9 | 32.2 | 32.6 | 31.2 | 32.2 |
| 25 Max | 31.9 | 32.4 | 32.0 | 32.1 | 32.3 | 32.4 | 32.1 | 32.6 | 31.6 | 32.3 | 30.7 | 31.9 |
| 25 Min | 31.7 | 32.2 | 31.8 | 31.7 | 31.9 | 31.9 | 31.8 | 32.1 | 31.4 | 32.1 | 30.0 | 31.5 |
| 26 Max | 32.0 | 32.9 | 32.2 | 32.3 | 32.6 | 32.0 | 32.3 | 32.6 | 31.6 | 32.6 | 31.2 | 32.9 |
| 26 Min | 31.9 | 32.7 | 32.1 | 32.1 | 32.1 | 32.4 | 32.0 | 32.5 | 31.7 | 32.1 | 30.8 | 31.9 |
| 27 Max | 32.1 | 32.7 | 32.3 | 32.3 | 32.3 | 32.4 | 32.2 | 32.6 | 32.0 | 32.4 | 31.2 | 32.6 |
| 27 Min | 31.8 | 32.2 | 31.9 | 31.9 | 32.1 | 32.1 | 31.9 | 32.3 | 31.8 | 32.0 | 31.0 | 31.7 |
| 28 Max | 32.1 | 32.9 | 32.3 | 32.3 | 32.6 | 32.7 | 32.3 | 32.6 | 31.9 | 32.6 | 31.1 | 32.2 |
| 28 Min | 31.9 | 32.4 | 31.9 | 32.0 | 32.3 | 32.3 | 32.1 | 32.5 | 31.7 | 32.2 | 31.0 | 31.8 |
| Monthly range | 2.84 | 0.36 | 4.04 | 0.51 | 3.88 | 0.50 | 4.43 | 0.47 | 4.11 | 0.57 | 3.64 | 0.81 |

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FIG. 51.

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The data show that when the soils were frozen there was very little variation in temperature at both depths not only within the same soil but also among the different soils, as evidenced by the results of March when all the soils were still frozen. Immediately upon thawing and also after that until the next freezing commenced the amplitude of the upper 5 inch depth was quite marked, both within the same soil and among the different soils. In the 18 inch depth, it was comparatively small. At both depths, the soil with 3.32% organic matter gave the greatest variation in temperature followed by the soils with 2.01, 5.47, 1.81, 6.95% organic matter and lastly by pure peat. Evidently the soils with the medium amounts of organic matter gave the greatest amplitude while those with the opposite extreme of organic matter gave the smallest. This was exactly the way that their average temperature behaved.

The fluctuations of the temperature of the soils with the various amounts of organic matter did not vary greatly among themselves within the same day or month, but they varied with peat. It will be seen that the differences between the amplitudes of the former soils in the upper 5 inches varied about 2° F. the most after the month of April, but the differences between these fluctuations and those of peat were comparatively very large, ranging in the month of June for instance, 12.72° F. between the peat and the soil with 3.32% organic matter.

In the 18 inch depth the amplitudes tended to increase with the decrease in organic matter. The variations among the different soils, including the peat, ran in about the same order of magnitude as in the upper depth.

The highest daily amplitude for the 5 inch depth occurred on April 30, and the highest monthly occurred in June for both depths. June is followed in order by May, July, August, September, April, October, November, and December.

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## SEASONAL AND YEARLY AVERAGE AND RANGE OF TEMPERATURE.

TABLE 70 - SEASONAL AND YEARLY AVERAGE TEMPERATURES OF THE SOIL WITH DIFFERENT AMOUNT OF ORGANIC MATTER

| Season. | 1.81% Org. Mat. | | 2.08% Org. Mat. | | 3.32% Org. Mat | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Peat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5" | 18" | 5" | 18" | 5" | 18" | 5" | 18" | 5" | 18" | 5" | 18" |
| Spring: | | | | | | | | | | | | |
| March | 29.97 | 31.03 | 30.55 | 31.44 | 30.84 | 31.68 | 30.65 | 31.46 | 30.72 | 31.36 | 30.06 | 31.42 |
| April | 42.04 | 37.82 | 43.64 | 38.27 | 44.19 | 37.41 | 43.00 | 38.12 | 41.84 | 37.53 | 35.38 | 31.68 |
| May | 57.89 | 53.15 | 60.45 | 53.86 | 60.81 | 53.90 | 60.22 | 53.60 | 59.66 | 53.68 | 54.93 | 49.04 |
| Ave. | 43.30 | 40.67 | 44.88 | 41.19 | 45.28 | 41.00 | 44.62 | 41.06 | 44.07 | 40.86 | 40.12 | 37.38 |
| Summer: | | | | | | | | | | | | |
| June | 67.93 | 63.02 | 70.24 | 63.80 | 70.78 | 64.10 | 70.70 | 63.89 | 70.51 | 64.12 | 64.12 | 62.88 |
| July | 72.85 | 69.58 | 74.55 | 70.03 | 75.23 | 70.11 | 74.85 | 69.77 | 74.93 | 69.99 | 72.81 | 69.41 |
| August | 68.52 | 66.40 | 70.36 | 67.04 | 70.77 | 67.19 | 70.15 | 66.78 | 70.52 | 66.96 | 68.55 | 66.55 |
| Ave. | 69.77 | 66.33 | 71.72 | 66.96 | 72.26 | 67.13 | 71.90 | 66.81 | 71.99 | 67.91 | 68.49 | 66.28 |
| Autumn: | | | | | | | | | | | | |
| September | 65.69 | 64.93 | 66.96 | 65.57 | 67.15 | 65.68 | 66.96 | 65.50 | 66.61 | 65.53 | 65.80 | 65.81 |
| October | 49.93 | 51.37 | 50.85 | 52.04 | 50.11 | 52.41 | 50.93 | 52.34 | 50.70 | 52.63 | 50.26 | 53.37 |
| November | 38.72 | 41.60 | 39.58 | 42.80 | 39.68 | 43.34 | 39.92 | 43.46 | 39.97 | 43.63 | 40.45 | 44.67 |
| Ave. | 51.45 | 52.63 | 52.46 | 53.47 | 52.31 | 53.81 | 52.60 | 53.77 | 52.43 | 53.93 | 52.17 | 54.62 |
| Winter: | | | | | | | | | | | | |
| December | 31.81 | 35.42 | 32.87 | 36 50 | 33.99 | 37.00 | 33.25 | 37.00 | 33.43 | 37.17 | 34.18 | 38.13 |
| January- 1913 | 30.68 | 33.58 | 31.54 | 34.46 | 31.75 | 34.95 | 32.00 | 34.95 | 31.99 | 35.02 | 32.18 | 35.71 |
| February | 26.19 | 30.50 | 26.88 | 31.52 | 27.10 | 31.93 | 27.53 | 31.73 | 27.48 | 31.99 | 28.66 | 33.23 |
| Ave. | 29.59 | 33.17 | 30.43 | 34.16 | 30.95 | 34.63 | 30.93 | 34.56 | 30.97 | 34.73 | 31.67 | 35.69 |
| Yearly average | 48.52 | 48.20 | 49.87 | 48.95 | 50.45 | 49.14 | 50.01 | 49.05 | 49.87 | 49.16 | 48.11 | 48.49 |

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TABLE 71.—SEASONAL AND YEARLY RANGE OF TEMPERATURES OF THE SOIL WITH DIFFERENT AMOUNT OF ORGANIC MATTER.

| Season. | 1.81% Org. Mat. | | 2.08% Org. Mat. | | 3.32% Org. Mat. | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Org. Mat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| Spring: | | | | | | | | | | | | |
| March | 0.68 | 0.52 | 0.67 | 0.56 | 0.79 | 0.44 | 0.66 | 0.52 | 0.57 | 0.64 | 0.72 | 0.48 |
| April | 5.23 | 1.60 | 9.85 | 1.39 | 10.33 | 1.55 | 8.29 | 0.93 | 7.03 | 0.69 | 2.57 | 0.28 |
| May | 11.59 | 2.38 | 13.40 | 1.89 | 13.67 | 1.56 | 12.40 | 1.15 | 11.36 | 0.92 | 3.07 | 0.96 |
| Ave | 5.83 | 1.50 | 7.98 | 1.28 | 8.26 | 1.18 | 7.12 | 0.87 | 6.32 | 0.75 | 2.12 | 0.57 |
| Summer: | | | | | | | | | | | | |
| June | 13.48 | 2.52 | 14.92 | 2.08 | 15.44 | 1.47 | 14.20 | 1.20 | 13.51 | 0.97 | 2.71 | 0.33 |
| July | 12.57 | 2.29 | 12.63 | 1.90 | 12.63 | 1.51 | 11.40 | 1.25 | 11.25 | 1.10 | 2.96 | 0.64 |
| August | 10.77 | 2.15 | 12.07 | 1.85 | 12.34 | 1.49 | 11.29 | 1.37 | 10.73 | 1.22 | 2.82 | 0.63 |
| Ave | 12.27 | 2.32 | 13.21 | 1.94 | 13.47 | 1.49 | 12.30 | 1.27 | 11.83 | 1.10 | 2.83 | 0.53 |
| Autumn: | | | | | | | | | | | | |
| September | 10.31 | 1.97 | 11.23 | 1.56 | 11.80 | 1.25 | 10.65 | 0.43 | 9.80 | 1.00 | 2.55 | 0.58 |
| October | 8.14 | 2.04 | 8.78 | 1.63 | 9.19 | 1.53 | 7.99 | 1.18 | 7.51 | 0.97 | 2.41 | 0.60 |
| November | 3.81 | 1.25 | 3.83 | 0.95 | 3.78 | 1.09 | 3.31 | 0.99 | 3.01 | 0.41 | 1.06 | 0.50 |
| Ave | 7.42 | 1.75 | 7.95 | 1.38 | 8.28 | 1.29 | 7.32 | 0.87 | 6.77 | 0.79 | 2.01 | 0.56 |
| Winter: | | | | | | | | | | | | |
| December | 2.43 | 0.74 | 2.08 | 0.63 | 1.91 | 0.57 | 1.55 | 0.59 | 1.24 | 0.56 | 0.70 | 0.43 |
| January—1913 | 0.92 | 0.38 | 0.76 | 0.36 | 0.66 | 0.32 | 0.64 | 0.32 | 0.62 | 0.31 | 0.36 | 0.30 |
| February | 3.64 | 0.81 | 4.11 | 0.57 | 4.43 | 0.47 | 3.88 | 0.50 | 4.04 | 0.51 | 2.04 | 0.36 |
| Ave | 2.33 | 0.64 | 2.32 | 0.52 | 2.33 | 0.45 | 2.02 | 0.47 | 1.97 | 0.48 | 1.03 | 0.36 |
| Yearly range | 6.96 | 1.55 | 7.95 | 1.28 | 8.08 | 1.10 | 7.19 | 0.87 | 6.72 | 0.75 | 2.60 | 0.51 |

Table 70 shows that the average temperature of all the soils was highest in summer and was followed in order by autumn, spring and lastly by winter. The temperature of all the different soils was somewhat different at the various seasons, with the greatest variation occurring in the spring and the least in the winter. In the spring and summer seasons the soil with 3.32% organic content exhibited the highest temperature at both depths, with the soils containing 2.08, 5.47, 6.95, 1.81% and peat came next in order. In the fall season, with the exception of the soil with 1.81% organic matter, the temperature was practically the same for all the other soils. For the winter season the soil with 1.81% organic matter had the lowest temperature and the peat the highest, while the temperature of the soils with 2.08, 3.32, 5.47 and 6.95% organic matter was intermediate and about the same for all of them. When the averages for the year are examined, it is found that the temperature of the soil with 1.81% organic matter and that of peat was almost the same but less than that of the soils with the intermedi-

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ate percentages of organic matter; the temperature of these latter soils was also almost the same.

From table 71 it is seen that the highest seasonal amplitude occurred in summer, then in autumn, spring and winter. The greatest variation in the amplitude of the different soils was shown in the spring and the least in winter. Throughout all the seasons the soil with 3.32% organic matter exhibited the largest amplitude with the soils containing 2.01, 5.47, 6.95, and 1.81% and peat followed in order. This order maintained itself also for the year.

## COMPARISON BETWEEN MONTHLY AVERAGE AND RANGE OF TEMPERATURE OF THE AIR AND THE SOILS.

TABLE 72.—COMPARISON BETWEEN THE MONTHLY AVERAGE TEMPERATURES OF THE AIR AND OF THE SOIL WITH DIFFERENT AMOUNTS OF ORGANIC MATTER.

| Per cent Org Matter | March | | April | | May | | June | | July | | August | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1.81% | 29.97 | 31.03 | 42.04 | 37.82 | 57.89 | 53.15 | 67.93 | 63.02 | 72.85 | 69.58 | 68.52 | 66.40 |
| 2.01% | 30.55 | 31.44 | 43.64 | 38.27 | 60.45 | 53.86 | 70.24 | 63.80 | 74.55 | 70.03 | 70.36 | 67.04 |
| 3.32% | 30.84 | 31.68 | 44.19 | 37.41 | 60.81 | 53.90 | 70.78 | 64.10 | 75.23 | 70.11 | 70.77 | 67.19 |
| 5.47% | 30.65 | 31.46 | 43.00 | 38.12 | 60.22 | 53.60 | 70.70 | 63.89 | 74.85 | 69.77 | 70.15 | 66.78 |
| 6.95% | 30.72 | 31.36 | 41.84 | 37.53 | 59.66 | 53.68 | 70.51 | 66.78 | 74.93 | 69.99 | 70.52 | 66.96 |
| Peat | 30.06 | 31.42 | 35.38 | 31.68 | 54.93 | 49.04 | 64.12 | 62.88 | 72.81 | 69.41 | 68.55 | 66.55 |
| Air | 28.38 | | 50.22 | | 62.00 | | 70.78 | | 75.77 | | 72.34 | |

| Per cent Org. Matter. | September | | October | | November | | December | | January, 1913. | | February. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1.81% | 65.69 | 64.93 | 49.93 | 51.37 | 38.72 | 41.60 | 31.81 | 35.42 | 30.68 | 33.58 | 26.19 | 30.50 |
| 2.01% | 66.96 | 65.57 | 50.85 | 52.04 | 39.58 | 42.80 | 32.87 | 36.50 | 31.54 | 34.46 | 26.88 | 31.52 |
| 3.32% | 67.15 | 65.68 | 50.11 | 52.41 | 39.68 | 43.34 | 32.99 | 37.00 | 31.75 | 34.95 | 27.10 | 31.93 |
| 5.47% | 66.96 | 65.50 | 50.93 | 52.37 | 39.92 | 43.46 | 33.25 | 37.00 | 32.00 | 34.95 | 27.53 | 31.73 |
| 6.95% | 66.61 | 65.53 | 50.70 | 52.63 | 39.97 | 43.63 | 33.43 | 37.17 | 31.99 | 35.02 | 27.48 | 31.99 |
| Peat | 65.80 | 65.81 | 50.26 | 53.37 | 40.45 | 44.67 | 34.18 | 38.13 | 32.18 | 35.71 | 28.66 | 33.23 |
| Air | 68.90 | | 54.55 | | 41.71 | | 30.58 | | 26.44 | | 20.63 | |

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TABLE 73.—COMPARISON BETWEEN MONTHLY RANGE OF TEMPERATURE OF THE AIR AND OF THE SOIL WITH DIFFERENT AMOUNTS OF ORGANIC MATTER.

| Per cent Org. Matter | March | | April | | May | | June | | July | | August | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1.81% | 0.68 | 0.52 | 5.23 | 1.60 | 11.59 | 2.38 | 13.48 | 2.52 | 12.57 | 2.29 | 10.77 | 2.15 |
| 2.01% | 0.67 | 0.56 | 9.85 | 1.39 | 13.40 | 1.89 | 14.92 | 2.08 | 12.63 | 1.90 | 12.07 | 1.85 |
| 3.32% | 0.79 | 0.44 | 10.33 | 1.55 | 13.67 | 1.56 | 15.44 | 1.47 | 12.63 | 1.51 | 12.34 | 1.49 |
| 5.47% | 0.66 | 0.52 | 8.29 | 0.93 | 12.40 | 1.15 | 14.20 | 1.20 | 11.40 | 1.25 | 11.29 | 1.37 |
| 6.95% | 0.57 | 0.64 | 7.03 | 0.69 | 11.36 | 0.92 | 13.51 | 0.97 | 11.25 | 1.10 | 10.73 | 1.22 |
| Peat | 0.72 | 0.48 | 2.57 | 0.28 | 3.07 | 0.96 | 2.71 | 0.33 | 2.96 | 0.64 | 2.82 | 0.63 |
| Air | 30.49 | | 31.12 | | 32.48 | | 41.06 | | 36.98 | | 34.18 | |

| Per cent Org. Matter | September | | October | | November | | December | | January, 1913 | | February | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ |
| 1.81% | 10.31 | 1.97 | 8.14 | 2.04 | 3.81 | 1.25 | 2.43 | 0.74 | 0.92 | 0.38 | 3.64 | 0.81 |
| 2.01% | 11.23 | 1.56 | 8.78 | 1.63 | 3.83 | 0.95 | 2.08 | 0.63 | 0.76 | 0.36 | 4.11 | 0.57 |
| 3.32% | 11.80 | 1.25 | 9.19 | 1.53 | 3.78 | 1.09 | 1.91 | 0.57 | 0.66 | 0.32 | 4.43 | 0.47 |
| 5.47% | 10.65 | 0.43 | 7.99 | 1.18 | 3.31 | 0.99 | 1.55 | 0.59 | 0.64 | 0.32 | 3.88 | 0.50 |
| 6.95% | 9.80 | 1.00 | 7.51 | 0.97 | 3.01 | 0.41 | 1.24 | 0.56 | 0.62 | 0.31 | 4.04 | 0.51 |
| Peat | 2.55 | 0.58 | 2.41 | 0.60 | 1.06 | 0.50 | 0.50 | 0.43 | 0.36 | 0.30 | 2.04 | 0.36 |
| Air | 35.45 | | 31.57 | | 19.91 | | 14.92 | | 15.41 | | 15.75 | |

The foregoing two tables show that the average air temperature was above the soil temperature of all depths from April to December inclusive, and below it during the months of January, February, and March. While the range of the air temperature was far greater than that of the soils and was above that of the latter throughout the year.

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## TEMPERATURE OF CULTIVATED, UNCULTIVATED, AND SOD LAND.

### OBJECT AND METHOD OF EXPERIMENTATION.

The object of this research was to study the temperature of land under cultivated, uncultivated, and sod conditions. A few workers have already made casual observations on this line of study but no one has conducted a very thorough and extensive investigation. It was to supply the latter need that this experiment was undertaken.

The experiment was commenced in November, 1911, and the temperature of the soil under the above treatments was measured at two different depths, 7 and 20 inches respectively, by means of soil thermographs which were procured from Friez, Baltimore, Maryland. There were four thermographs, two of which were double and two single. The former were made by special order and had two soil bulbs instead of one. One of the single soil thermographs registered the air temperature also.

The ideal way to study soil temperature, in order to get the absolute maximum and minimum, would be by means of such instruments as these if they were accurate and dependable. Unfortunately, they do not always possess these qualities. On account of the large mass of liquid in the bulbs, they are slow to respond to variations of temperature; the pen is too thick, and hence, the line is too heavy for accurate readings. Again, the setting of the recording sheets around the clock is not always exactly the same for the different times. The most serious defect, however, is that the standardization is only relative, not absolute, and if a small change takes place, the experimentor may not detect it. Furthermore, the bulbs may leak and in such a case the records are worthless. This unfortunate occurrence happened twice in the present work, and hence, has broken the continuous records. The bulbs at the depth of 20 inches of the uncultivated and sod plots began to leak in January and the records of this depth of both plots were lost from this time on till May when the defective bulbs were repaired. Since the thermographs of both plots were double, the bulbs of the upper 7 inches also had to be removed in order to repair those at the lower depth, and hence, the records of the upper depths were also lost during the month of April, after the thawing had taken place. On the whole, however, these instruments gave quite satisfactory results.

In order not to disturb the natural condition of the ground the bulbs were placed in the following manner: Small trenches were dug in the ground 20 inches deep, 6 inches wide and 20 inches long. At one end of these trenches wooden rods of the same diameter as the bulbs were bored into the soil horizontally at the proper depths. The rods were then taken out, the bulbs put in their place and the trench filled up with the excavated soil. In this manner the bulbs were kept under undisturbed ground and the records, therefore, may be considered to be of soils under natural conditions right from the start.

The ground on which the plots were situated was very smooth and

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slightly rolling. The soil consisted of a sandy loam. The ground had been under alfalfa sod for several years, and from the plots, which were to be left uncultivated and cultivated, the vegetation was removed long before the experiment was commenced. The plots were 20x15 feet and the bulbs were placed about 5 feet apart from each plot. The thermographs were located on top of posts 4 feet high.

The uncultivated plot was kept free from weeds, while the cultivated plot was worked always immediately after a rain. The sod plot was mowed the first of May at the time when the bulbs were placed in the soil after they were repaired. From this time on the vegetation was never cut again. Throughout the growing season, the crop grew luxuriantly and was very dense.

On account of space, the data of this experiment cannot be presented as fully and as detailed as in the preceding experiments. In the following tables, therefore, is not shown the daily temperature but only the monthly.

MONTHLY AVERAGE TEMPERATURE.

TABLE 74—AVERAGE MONTHLY TEMPERATURE OF UNCULTIVATED, CULTIVATED, AND SOD LAND.

| Name of month | Uncultivated | | Cultivated | | Sod | |
|---|---|---|---|---|---|---|
| | 7" | 20" | 7" | 20" | 7" | 20" |
| December | 34.5°F | 36.62°F | 34.84°F | 35.94°F | 34.38°F | 37.07°F |
| January | 27.73 | ..... | 27.79 | 30.92 | 29.22 | ..... |
| February | 30.73 | ..... | 29.42 | 30.06 | 30.07 | ..... |
| March | 31.81 | ..... | 30.60 | 30.67 | 30.81 | ..... |
| April | 42.24 | ..... | 39.63 | 37.10 | 41.93 | ..... |
| May | ..... | ..... | 54.12 | 50.88 | ..... | ..... |
| June | 65.25 | 62.00 | 64.4 | 60.64 | 61.97 | ..... |
| July | 71.09 | 66.94 | 70.04 | 66.61 | 65.55 | 64.0 |
| August | 66.60 | 63.80 | 66.24 | 63.75 | 63.39 | 63.74 |
| September | 63.48 | 61.90 | 62.80 | 61.84 | 59.60 | 61.40 |
| October | 50.24 | 50.89 | 50.46 | 50.90 | 48.46 | 52.43 |
| November | 39.77 | 41.20 | 39.50 | 41.27 | 39.85 | 45.07 |

It will be seen that in December all the plots at the depth of 7 inches had practically the same temperature. In January, the coldest month of the year, the sod plot was about 1.5 F. warmer than the other two plots, while the latter had nearly the same temperature. In the months of February and March the temperature of all the soils was almost the same with a small difference in favor of the uncultivated plot. In April the uncultivated plot had the highest temperature and was followed by the sod and finally by the cultivated. During the months of June, July, August, and September, the uncultivated plot was the warmest, the sod the coldest, while the cultivated was intermediate. The difference between the cultivated and uncultivated plots was not very great, the highest variation occurred in July (1.05° F.), followed by June (.85°), September (68°) and August (.364°). The amplitude between the sod and either of the bare plots was quite marked, ranged in July as much as about 5° F. After October the order of warmth of these plots changed somewhat. The sod which since May had the lowest temperature had now the highest, with the uncultivated and cultivated

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plots next in order. The latter two soils had practically the same temperature, the difference in favor of the uncultivated plot was very slight.

The daily records, which are not shown in the above table, show that the lowest fall in temperature occurred on January 7 when the average temperature of the different soils at the 7 inch depth was as follows: cultivated 24.55°, uncultivated 22.0°. and sod 27.85°, while the highest average temperature took place on July 9 with the following results: 7 inch cultivated 76.00°, uncultivated 77.80°, sod 69.45°; 20 inch cultivated 69.0°, uncultivated 69.31°, sod 65.25°.

The first freezing occurred on December 28th. On this day the cultivated and uncultivated plots at the 7 inch depth froze at the same time, while the sod plot froze 7 days later (January 5). The first thawing took place on April 5th when both the uncultivated and the sod plots thawed at the same time. The other plot thawed about a day later.

In the second winter (1912-13) the different plots froze at the upper depth as follows: cultivated December 11th, uncultivated December 11th, sod December 13th. At the 20 inch depth the uncultivated froze Jan. 20th, cultivated Jan. 22, and sod did not freeze at all. Throughout this winter the sod plot maintained the highest temperature at both depths, the temperature of the other two plots was about he same. The results of the second winter, therefore, are in agreement with those of the first winter, the only difference being that in the second winter the effect of the vegetation in keeping the soil warm was more pronounced, due undoubtedly to the greater abundance and greater thickness of the layer of vegetation.

The foregoing data show, then, that the conditions of cultivation, non-cultivation, and sod have a very distinct influence upon soil temperature. Especially interesting is the influence of vegetation. It was observed in the first spring that the sod plot thawed at the same rate as the bare and uncultivated plot, and that its temperature rose immediately several degrees above that of the latter and remained so for the next 10 days when the plants began to grow, and then its temperature dropped back and stayed much lower than the temperature of both bare plots until September 25th. From this date on the temperature of the other two plots fell below that of the sod plot and remained so throughout the second winter and up to the middle of the second spring.

The cooling and warming effect of the cover crop in both the warmer and colder seasons of the year is self evident. In summer time the growing crop keps the soil temperature low for the following reasons: (1) Practically all the sun rays are intercepted by the growing vegetation so that the ground surface is nearly all shaded, and its temperature rise is dependent upon the wind currents and convections; (2) the air temperature around the plants and at the surface of the ground is low on account of the great amount of transpiration and evaporation that takes place. The process of evaporation has a most tremendous influence upon the diminution of temperature. The amount of transpiration by plants is not inconsiderable. Mulham makes the statement that areas covered with vegetation under the same conditions evaporate about one-third more water than a free water surface.

In the cold part of the year, the decayed and partially decayed vegetation acts as a blanket over the surface soil. This blanket performs several functions, chief of which are: First, and most important, the

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prevention of the cold currents of air from coming in contact with the surface soil and thereby cooling it; second, the layer of dead vegetation, and especially when it is quite thick, is porous and the spaces are filled with air. This air being a very poor conductor of heat, does not transmit very rapidly the heat of the soil to the air above, and as a result the soil loses its heat less rapidly than if it were unprotected. Even in the summer time, the vegetation, though it is growing, acts as a blanket, and prevents the loss of heat, as evidenced by the very unappreciable variation that exists between the daily maximum and minimum temperature.

That the vegetation acts as a blanket and tends to prevent the loss of heat from the soil was confirmed also by the following experiment: A plot was covered with straw, and its fall of temperature was compared with that of a plot which remained unprotected. The results show that the uncovered soil froze at the depth of 7 inches on December 11, while that covered with straw froze on February 14th. On certain very cold nights the ground covered with straw remained as much as 10° F. warmer than the unprotected ground.

What is true of the retarding effect of vegetation on the cooling of the soil in the fall and winter applies also to its warming in the spring. If the ground has a very thick layer of dead vegetation the slow rate of warming will be evident. This does not necessarily mean, however, that the soil will have a low daily average temperature because, while the vegetation, which acts as a blanket, will prohibit a very high rise of temperature during the day it will equally prevent a very low fall of temperature during the night, and since the trend of the temperature is upward, the sod land or the land covered with straw will have a higher temperature during the early spring, especially during rapid alternation of cold and warm days, than a bare and uncultivated soil, which on account of its condition, permits greater and more nearly proportional extremes of temperature. These facts find confirmation in the present experiment. In the first spring the sod and uncultivated plots thawed on the same day and the temperature of the former plot rose several degrees higher than that of the latter, and also of the cultivated plot, within the next few days, as has already been shown. Unfortunately the thermographs were removed at this time (April) for repairs and consequently it cannot be stated how long the temperature of the sod land would have continued to be higher than that of the other plots and especially of the uncultivated plot. The uninterrupted records of the second spring, however, supply the data for this point and show that the temperature of the sod plot remained above that of the other plots until the beginning of May, when the vegetation had grown considerably. The second spring's results also show that the sod plot thawed about the same time as the other plots and that its temperature rose above that of the latter. Its average increase of temperature over the cultivated plot was 1.82° F. and over the uncultivated plot 2.34° F., for the month of April. Evidently the results of the second spring agree very well with those of the preceding spring.

The interesting question that suggests itself in connection with the temperature of soils thickly covered with crops is whether the plants themselves conduct heat into the soil, since the temperature of the latter is far below that of the air.

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No positive statement can be made on either side of this question because there is no experimental data on record. Arguing theoretically, however, it would seem that the soil receives no heat or only a very unappreciable amount in this manner; first, because the plants themselves are poor conductors of heat; and second, on account of the fact that there is a tremendous amount of evaporation or transpiration going on from the surface of the plants. Since this evaporation tends to lower the surrounding temperature very markedly, the air temperature around and between the plants may not be very high or but little higher than that of the soil. Nor would it seem likely that in the cold period of the year or during the night the plants would be effective in appreciably cooling the soil by mere conduction.

The difference in temperature between the cultivated, and uncultivated plots is very interesting and needs special notice. This difference in temperature is more complex than it is commonly thought, and our present knowledge and interpretation of it are very incomplete and somewhat faulty. The common belief is that the uncultivated soil is always warmer than the cultivated during the warm part of the year. The reason given for this is that the former soil being a good conductor of heat on account of its compact condition, allows the heat to travel through it faster and to greater depths. This heat during the night recedes from the lower strata to the surface and keeps the upper layers warm, while the cultivated soil, on account of its loose state, is a poor heat propagator, and allows the heat to penetrate downward very slowly and only to a shallow depth. This soil, therefore, during the day will become very hot on the top or upper depth and during the night very cold.

The results which have been obtained in the last two years do not bear out these beliefs entirely. In the first place, the uncultivated soil is not always warmer than the cultivated during the warm part of the year, but only during certain seasons or times of this part of the year, and under certain conditions; and in the second place, the explanation given for the existing or observed difference in temperature between these two differently managed soils is neither complete, nor entirely correct.

The results obtained show that immediately after thawing in the spring the average daily temperature of the cultivated soil 7 inches deep, rose gradually above that of the uncultivated and continued to remain in excess until about the middle of May, and then the order was reversed. The average temperature of the cultivated plot for the month of April, in the spring of 1913, was 0.52° F. higher than that of the uncultivated. The records for the same month for the spring of 1912 are not so complete but those that are available tend to confirm the above general order. The uncultivated soil absorbed a greater amount of heat during the day time than the cultivated but also lost a correspondingly greater quantity of heat during the night than the latter soil. The gain and loss in heat in the uncultivated soil appears to be more nearly proportional than in the cultivated soil. The average maximum and minimum temperature for the month of April was for the uncultivated soil 47.81° and 41.80° F. and for the cultivated 47.47° and 43.17° F., respectively. The rise of temperature in the cultivated



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ground was starting in the morning, therefor, at a higher point, sometimes more than 3° F. higher, than in the uncultivated, so that the latter soil had to gain almost twice the amount of heat in order that its average or even its maximum temperature might equal that of the former. What brought about this gradual gain in heat in the cultivated soil will be explained subsequently. During all this time, however, that the temperature of the upper depth of the cultivated soil was higher than that of the uncultivated, the temperature of the lower depth or 20 inches of both soils was practically the same. As soon, however, as the temperature of the lower depth of the undisturbed soil began to rise higher than that of the disturbed, the temperature of the upper depth of the former also began to rise higher than that of the latter, and continued to be higher until about October. This is a strong indication that the temperature of the lower depths influences somewhat that of the upper depth, and it is probably this factor which causes the uncultivated soil, at the upper depth, to have a higher temperature than the cultivated soil, at the same depth, during the warmest part of the year.

The foregoing description of the behavior of the temperature of the cultivated and uncultivated soils, shows, therefore, that the uncultivated or compact soil is not always the warmer of the two, in the warm part of the year, as is commonly believed, but only during the warmest part of the year, and perhaps under certain conditions during the other warm seasons. The question now is what factor or factors bring about or cause this difference in temperature. The possible explanations may be found in the following general facts: When a soil is cultivated the area of its surface exposed is by far greater than that of a compacted or undisturbed soil, and of necessity the amount of evaporation in the former is greater than in the latter. As a result of this difference in evaporation the temperature of the cultivated soil does not rise, at the beginning, as high as that in the uncultivated. As soon, however, as a dry mulch is formed on the disturbed soil its loss of moisture by evaporation is reduced considerably, while the loss in the undisturbed soil is still large and consequently its rise of temperature is small. On the other hand, the heat that is not expended in the evaporation of water is rapidly conducted downward in the case of the uncultivated soil, while in the case of the cultivated soil only part of the heat is conducted downward the other part is radiated back to the atmosphere by the dry mulch at the top. This dry mulch forms a very poor and imperfect contact with the moist soil below and as a result acts as a blanket, analogous to a growing crop or a cover of straw, and does not impart all its heat to the soil below. When this mulch becomes completely dry it gets very hot during the sun insolation, in fact hotter than the air above, and a large amount of this excessive heat is radiated back to the atmosphere. This fact was proved by the following series of experiments: The bulbs of mercury thermometers were placed one inch above the surface of both the cultivated and uncultivated soils and it was found that the thermometer over the cultivated soil registered at certain days from 9 to 18° F. higher than that placed over the uncultivated soil. In another experiment the bulbs of the thermometers were placed horizontally over the surface of both soils and it was found also in this case that the surface of the cultivated soil was about 10° F. warmer than that of the uncultivated soil. In still another experiment the bulbs were simply covered

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with the very top surface material from both plots and the results obtained were in the same order and degree of magnitude as the foregoing. All these results go to show, therefore, that a large amount of heat which is received by the surface of the cultivated soil is radiated back to the atmosphere, which accounts for its small rise of temperature during the day. The objection may be raised, however, that the greater temperature on and above the surface of the cultivated over the uncultivated soil, was probably due to the greater amount of evaporation of water in the latter. This is partly correct, and especially when the soils are very moist and the capilary action is very active, but the same results were obtained when the soils had practically the same percent of moisture.

The foregoing explanation concerning the difference in temperature between the cultivated and uncultivated soil is further confirmed by the following experiment. Wooden boxes, 12 inches square and 2 inches high, were filled with moist quartz sand. In one series the sand was well compacted and in another it was cultivated. These two series of sands were then placed outdoors during very hot days and their temperature was recorded every 15 or 30 minutes from morning till evening for two succeeding days. The results obtained are shown in the following table:

TABLE 75 — TEMPERATURE BETWEEN CULTIVATED AND UNCULTIVATED SAND—FIRST DAY.

| Time | 9:00 a. m. | 9:15 | 9:30 | 9:45 | 10:00 | 10:15 | 10:30 | 10:45 |
|---|---|---|---|---|---|---|---|---|
| Cultivated | 53.8 | 55.4 | 56.7 | 57.2 | 59.3 | 61.0 | 62.5 | 64.0 |
| Uncultivated | 54.2 | 56.5 | 57.9 | 59.8 | 61. | 63. | 64.4 | 65.6 |
| Time | 11:00 | 11:30 | 12:15 | 12:30 | 12:45 | 1:00 | 1:30 | 2:00 |
| Cultivated | 65.8 | 66.8 | 69.8 | 70.6 | 71.2 | 71.8 | 73.0 | 73.5 |
| Uncultivated | 67.4 | 67.8 | 70.4 | 70.8 | 71.3 | 71.6 | 71.7 | 71.7 |
| Time | 2:30 | 2:45 | 3:00 | 3:15 | 3:30 | 3:45 | 4:00 | 4:15 |
| Cultivated | 74.0 | 74.9 | 73.7 | 73.6 | 72.8 | 72.0 | 71.2 | 70.2 |
| Uncultivated | 71.0 | 71.0 | 70.4 | 69.8 | 68.7 | 67.8 | 66.8 | 65.9 |
| Time | 4:30 | 4:45 | 5:00 | 5:15 | 5:30 | 5:45 | 6:00 | 6:15 |
| Cultivated | 69.4 | 68.4 | 67.7 | 66.6 | 65 8 | 64.8 | 63.8 | 62.6 |
| Uncultivated | 65.0 | 64.0 | 63.0 | 62.2 | 61.2 | 60 3 | 59.5 | 58.2 |



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SECOND DAY

| Time | 7:00 a. m. | 7:15 | 7:30 | 7:45 | 8:00 | 8:15 | 8:30 | 8:45 | 9:00 |
|---|---|---|---|---|---|---|---|---|---|
| Cultivated..... | 50.2 | 52.2 | 54.2 | 56.0 | 58.0 | 60.0 | 61.8 | 63.5 | 65.2 |
| Uncultivated .. . | 51.4 | 53.8 | 56.2 | 58.3 | 60.7 | 63.1 | 65.2 | 67.4 | 69.6 |
| Time | 9:15 | 9:30 | 9:45 | 10:00 | 10:15 | 10:30 | 14:45 | 11:00 | 11:15 |
| Cultivated..... | 66.6 | 68.0 | 69.7 | 71.0 | 72.2 | 73.4 | 74.7 | 76.0 | 76.0 |
| Uncultivated.... | 71.4 | 73.2 | 75.1 | 76.6 | 78.0 | 79.4 | 80.8 | 82.2 | 82.2 |
| Time | 11:30 | 12:00 | 12:30 | 1:00 | 1:30 | 2:00 | 7:00 | 7:30 | 8:00 |
| Cultivated..... | 77.4 | 78.4 | 80.4 | 81.8 | 82.8 | 83.1 | 52.3 | 52.2 | 52.2 |
| Uncultivated..... | 83.6 | 84.6 | 86.4 | 87.6 | 88.6 | 86.6 | 48.8 | 48.7 | 48.7 |

This table bears out the foregoing explanation perfectly. It will be seen that at the beginning of the experiment the temperature of the cultivated sand did not rise as fast as that of the uncultivated. This was due to the large amount of evaporation in the case of the cultivated sand, partly on account of its greater area exposed and partly because more heat was accumulating at the surface; and to a less amount of evaporation and to a small quantity of heat accumulating at the surface, in the case of the uncultivated sand. By 1.00 o'clock, however, the temperature of the cultivated sand attained the same degree of magnitude as the other sand. From that time on the results were reversed, the cultivated sand attained and continued to have a higher temperature than the uncultivated. This is explained on the basis that as soon as the mulch was formed on the surface of the cultivated sand the evaporation was considerably cut down, while in the uncultivated sand it was still large. The amount of heat that was expended in evaporating the moisture of the uncultivated sand was apparently larger than that radiated back to the air by the dry mulch of the cultivated sand. On the second day the results were again reversed, the cultivated sand which in the latter part of the previous day had the highest temperature of the two sands, had now the lowest. This is again explained on the basis of the moisture content and of the effect of the dry mulch. The uncultivated sand lost most of its moisture in the previous day during the time that its temperature remained below that of the cultivated, while the latter lost less except at the beginning of the experiment. The result was that the uncultivated sand was losing now a less amount of heat by evaporation and consequently utilizing more of the air temperature for the raising of its own temperature, while the cultivated sand had still some moisture below the dry mulch and on account of the slow but continuous evaporation of this moisture, and also on account of the large amount of heat received being radiated back to the atmosphere by the dry mulch, this sand, therefore, was now utilizing a less amount of heat for the raising of its own temperature, and consequently its tem-

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perature was below that of the uncultivated sand. The moisture content of these series of sands was determined at the beginning and at the end of the experiment and it was found to be as follows: Initial percent moisture of both sands 8%; at end of experiment, cultivated sand 1.4%, uncultivated sand 1.30%. The cultivated sand would show a greater moisture content if the dry mulch had been excluded from both series of sands.

The dry mulch does not only prevent the soil from attaining a high temperature during the day but also prevents the soil from attaining a low temperature during the night. Its effect here is threefold: (1) it acts as a blanket and greatly reduces the rapid loss of heat; (2) it reduces the loss of heat by cutting down the radiation, as it has already been shown; and (3) it tends to conserve moisture in the lower strata and thereby increases the specific heat of the soil and consequently reduces the rate of cooling. It is partly on account of these effects, therefore, that the cultivated soil seems to be accumulating more heat during the early spring than the uncultivated soil, and to cool less rapidly during a severe cold weather.

The effectiveness of the dry mulch to conserve moisture is shown in the following table. This table contains the percent moisture content of all the different plots as determined during the different periods.

TABLE 76.—PERCENT MOISTURE OF THE DIFFERENT PLOTS.

| Date. | Uncultivated 7″ | Cultivated 7″ | Sod 7″ |
|---|---|---|---|
| April 4 | 21.52 | 23.61 | 17.37 |
| July 27 | 11.53 | 13.85 | 12.02 |
| September 9 | 14.56 | 15.47 | 10.83 |
| November 4 | 13.81 | 13.82 | 13.97 |

That the better heat conducting power of the uncultivated or compact soil over the cultivated or loose soil is not the greatest factor which causes the difference in temperature between these soils is further proved by the fact that the temperature begins to rise at the depth of 7 inches in the cultivated soil only about half an hour later, as has already been shown, than it does in the uncultivated soil. This is a strong evidence, that the loose soil below the dry mulch is not so poor a heat propagator as is commonly believed, and that it is not the main cause of the difference in temperature between these differently managed soils.

Summarizing the foregoing data, then, it has been seen that the uncultivated soil does not always have a higher temperature than the cultivated soil, during the warm part of the year, but only at the warmest part of this period and especially when the temperature of its lower depths is much higher than that of the corresponding depths on the cultivated soil, and that the factors which bring about the difference in temperature on these soils at the upper depths are (1) the dry mulch on the cultivated soil, (2) different rates of evaporation, (3) the different rate of heat propagation and (4) the higher temperature at the lower depths of the uncultivated over the cultivated soil.

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## MONTHLY RANGE OF TEMPERATURE.

TABLE 77.—MONTHLY RANGES OF TEMPERATURE OF THE UNCULTIVATED, CULTIVATED AND SOD PLOTS.

| Name of month. | Uncultivated. | | Cultivated. | | Sod. | |
|---|---|---|---|---|---|---|
| | 7" | 20" | 7" | 20" | 7" | 20" |
| December | .87 | .35 | .49 | .35 | .79 | .28 |
| January | 1.83 | ..... | 1.09 | .18 | .46 | .17 |
| February | .31 | ..... | .35 | .38 | .38 | ..... |
| March | .51 | ..... | .51 | .61 | .35 | ..... |
| April | 6.39 | ..... | 3.28 | 1.04 | 4.84 | ..... |
| May | ..... | ..... | ..... | ..... | ..... | ..... |
| June | 6.76 | .8 | 5.40 | .66 | 2.60 | ..... |
| July | 6.97 | 1.06 | 4.42 | .67 | 1.47 | .32 |
| August | 5.29 | .90 | 3.83 | .58 | 1.13 | .52 |
| September | 5.70 | 1.10 | 4.60 | 1.10 | 1.03 | .47 |
| October | 4.74 | 1.19 | 3.58 | 1.06 | 1.06 | .84 |
| November | 2.40 | .94 | 2.13 | 1.00 | .84 | .57 |

The foregoing table contains the monthly ranges between the maxima and minima temperature of the three different plots for the different months. It will be seen that the amplitude of the upper 7 inches of every plot increased from the winter months up to a certain time in the warm part of the year and then decreased. The maximum monthly amplitude that was reached was at different times for the various plots. For the cultivated it was in June, for the uncultivated July, and for the sod April. With the exception of the last month the variation between the highest and lowest temperature was greatest for the uncultivated, smallest for the sod and medium for the cultivated. The amplitude of the sod was very small indeed in comparison with that of the other plots.

The amplitude of the 18 inch depth is not as complete as that of the 7 inch depth but for those months that there are records for show that the magnitude was far below that of the upper depth, that it was greatest for the uncultivated, followed in order by the cultivated and finally by sod, and that the variation from month to month was not anywhere near as great, for any plot, as it was in the upper depth.

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## COMPARISON BETWEEN MONTHLY AVERAGE TEMPERATURE OF THE AIR AND OF THE DIFFERENT PLOTS.

TABLE 78.—COMPARISON BETWEEN MONTHLY AVERAGE TEMPERATURE OF THE AIR AND OF THE DIFFERENT PLOT.

| Soils. | December. | | January. | | February. | | March. | | April. | | May. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ |
| Uncultivated | 34.50 | 36.62 | 27.73 | ..... | 30.73 | ..... | 31.81 | ..... | 42.24 | ..... | ..... | ..... |
| Cultivated | 34.84 | 35.94 | 27.79 | 30.92 | 29.42 | 30.06 | 30.60 | 30.67 | 39.63 | 37.10 | 54.12 | 50.88 |
| Sod | 34.78 | 37.07 | 29.22 | ..... | 30.07 | ..... | 30.81 | ..... | 41.93 | ..... | ..... | ..... |
| Air | 31.90 | ..... | 10.80 | ..... | 17.15 | ..... | 27.87 | ..... | 50.57 | ..... | 61.61 | ..... |

| Soils. | June. | | July. | | August. | | September. | | October. | | November. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ | 7″ | 20″ |
| Uncultivated | 65.25 | 62.00 | 71.09 | 66.94 | 66.60 | 63.80 | 63 48 | 61.90 | 50.24 | 50.89 | 39.77 | 41.20 |
| Cultivated | 64.40 | 60.64 | 70.04 | 66 61 | 66 24 | 63.75 | 62.80 | 61.84 | 50.46 | 50.90 | 39.50 | 41.27 |
| Sod | 61.97 | ..... | 65.55 | 64.00 | 63.39 | 63.74 | 59.60 | 61.40 | 48.46 | 52.43 | 39.85 | 45.07 |
| Air | 70.47 | ..... | 75.71 | ..... | 72.75 | ..... | 68.58 | ..... | 54.39 | ..... | 41.59 | ..... |

The air temperature was above that of all the plots from April to December. The difference between the two classes of temperatures among the different plots varied in the different months.

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# EFFECT OF SOLUBLE SALTS ON THE RISING AND LOWERING OF TEMPERATURE OF SOILS.

## OBJECT AND METHOD OF EXPERIMENTATION.

Solutions possess many physical properties which have a very decided influence on temperature. Solutions of greater densities possess a lower freezing point, a higher boiling point, a lower vapor pressure, a higher surface tension and a higher viscosity, than solutions of lower concentration. All these properties vary with the composition of the solution and influence the rising and lowering of temperature either directly or indirectly. Soils, therefore, with different densities of solution will have different rising and lowering of temperature. Rising and lowering are employed here as general terms and are intended to include the rate of freezing, the degree of the lowering of the freezing point, the rate of thawing, the rate and degree of rising temperature, etc.

In the literature of soil temperature no record is found on the effect of soluble salts on the rising of soil temperature, but there is one work reported on the other phase of this subject. This is by Ulrich,[18] and it is on the influence of frosts on the temperature conditions of soils with different salt content. He conducted the investigation by mixing fine kaolin in cylinders with .05, 0.1 and 0.2 percent of $Co(OH)_2$, $NaCl_2$, $NaNo_3$, and some other salts and subjected the mixtures to temperatures varying from 0 to −10° C. The results show, in general, that the temperature of freezing was lowered by the addition of salts, the greater the amount of salt present the greater the lowering of temperature. When the soil water froze the temperature of the soil rose at once to 0° C., remained for a time at this point and then gradually fell under the influence of the low temperature. Certain salts, such as $Ca(OH)_2$, $CdCl_2$, etc., retarded this fall of temperature, others such as KOH, etc., hastened it.

In order to ascertain more positively, if possible, to what extent the cooling and warming of the soil is affected by the different soluble salts and what kind of salts have the greatest influence in either respect, the folowing experiments were undertaken. They consisted in placing equal amounts of quartz sand in wooden boxes, 12 inches square and 2 inches high with bottoms and no top, and then placing this sand in the boxes out doors on a stand to study either the lowering or rising of temperature. The quartz sand in the different boxes was previously thoroughly moistened with different solutions of various concentrations. These densities varied from one-half to three times normal. Where direct comparison was desired, either between the different concentrations within the same salt or between different salts, the same amounts of solution were added to equal weights of quartz sand. The study of the rising of temperature was conducted during clear hot days in summer, and that of the lowering of temperature was carried on during

[18] Forsch. a. d. G. a. Agrik. Phy. II : 218 – 229, 1897.

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cold evenings in the winter. In the former case, the temperatures were read on Centigrade thermometers reading from 0 to 110° and graduated to 0.1°, while in the latter case Fahrenheit thermometers were employed, especially constructed for the purpose which read from –32 to +100° and were graduated to 0.2°.

The data obtained for both studies are contained in the following pages. The results of the rising of temperature will be presented first.

## RISING OF TEMPERATURE.

Experiment 1. This was a preliminary experiment. It consisted of studying the effect of KCL on the rise of temperature in comparison with that of water. The solution was prepared by dissolving three times the molecular weight of the salt in one liter of water. Then 250 cc. of the solution as well as of water were added to portions of 6372 grams of quartz sand. The duplicate boxes containing the moist sand were then placed in the sun and the temperature records were taken at various times. The results obtained are given herewith:

TABLE 79.—EFFECT OF SALT SOLUTIONS ON THE RISE OF SOIL TEMPERATURE.

| Name of solution. | 9:30 a. m. | 11:00 a. m. | 1:00 p. m. | 4:00 p. m. | 9:00 p. m. |
|---|---|---|---|---|---|
| $H_2O$ | 21.00°C | 24.43°C | 28.68°C | 23.40°C | 17.43°C |
| KCl | 21.55 | 27.04 | 30.88 | 24.08 | 17.70 |

It will be seen that at the beginning the temperature of both $H_2O$ and KCL treated sand is practically the same, but that from then on the temperature of the KCL rises more rapidly than that of the water and at 1:00 P. M. when the maximum of both was reached, the difference is 2.20° C. in favor of the KCL treated sand. From that period on the temperature of both series falls and at 9:00 P. M. it is again about the same.

Experiment 2. In this experiment $NH_4Cl$, $NaNo_3$ and $CaCl_2$ were used. Their solutions were prepared by dissolving three times their normal molecular weight in one liter of water. Exactly 450 cc. of each solution was added to 5,770 grams of sand; the same number of cubic centimeters of water being also added to an equal weight of sand for comparison or as a standard. The moistened sand was then placed in the regular boxes and the temperature rise was studied on a warm clear day. The following are the results of this experiment:

TABLE 80.—EFFECT OF SOLUBLE SALTS ON THE RISE OF SOIL TEMPERATURE.

| Name of solution. | 9:00 a. m. | 11:30 a. m. | 1:30 p. m. | 5:30 p. m. |
|---|---|---|---|---|
| $H_2O$ | 20.85°C | 24.03°C | 22.90°C | 18.93°C |
| $NH_4Cl$ | 21.90 | 26.86 | 26.93 | 20.70 |
| $CaCl_2$ | 22.23 | 27.72 | 27.45 | 20.20 |
| $NaNo_3$ | 22.00 | 26.78 | 26.50 | 20.73 |

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As in the foregoing experiment these figures show that at 1:30 P. M. when the maximum temperature was reached, the sand treated with the different salts was much warmer than that treated with water. The highest temperature attained was by $CaCl_2$ and followed respectively by $NH_4Cl$, $NaNo_3$ and water. The amplitude between the $CaCl_2$ and water is 4.55°.

Experiment 3. In this experiment $K_2HPO_4$, $K_2CO_3$ and $K_2SO_4$ were employed and as usual their solutions were prepared by dissolving three times their equivalent molecular weight in one liter of water, then 460 cc. of each solution as well as of water were added to 6500 grams of sand. The temperature records were made in the manner already described and the following data were obtained:

TABLE 81.—EFFECT OF SOLUBLE SALTS ON THE RISE OF SOIL TEMPERATURE.

| Name of solution. | 8:45 a. m. | 11:25 a. m. | 1:30 p. m. | 6:30 p. m. |
|---|---|---|---|---|
| HBO | 23.40°C | 25.10°C | 27.20°C | 20.30°C |
| $K_2HPO_4$ | 23.15 | 27.53 | 31.20 | 21.40 |
| $K_2CO_3$ | 23.13 | 32.03 | 35.25 | 22.93 |
| $K_2SO_4$ | 23.55 | 29.48 | 32.38 | 21.83 |

This experiment gives more confirming evidence that the density of solution brings about a rising of temperature in soils. It is seen that at 1:30 P. M. the difference in temperature between pure water and $K_2CO_3$ is 8.05° in favor of the latter.

The difference observed in temperature between the last different salt solutions is partly due to unequal concentration because of different solubility of the salts. Only about half of the $K_2SO_4$ and about three-fourths of the $K_2HPO_4$ dissolved, while the whole amount of the $K_2CO_3$ went into solution.

Experiment 4. In the foregoing experiments different salts of the same density were used. In this experiment different densities of the same salt solution were tested. The salt used was NaCl in the proportion of 0.0, 1, 2, and 3 times its normal molecular weight in one liter of water. Exactly 460 cc. of each solution were added to 6500 grams of sand. The temperature data obtained are given below:

TABLE 82—EFFECT OF DIFFERENT DENSITIES OF SOLUTION ON THE RISE OF SOIL TEMPERATURE.

| Name of solution. | 9:00 a. m. | 11:15 a. m. | 1:00 p. m. | 2:30 p. m. |
|---|---|---|---|---|
| $H_2O$ | 19.73°C | 23.4 °C | 24.95°C | 24.75°C |
| 1-N NaCl | 19.13 | 25.8 | 27.63 | 27.13 |
| 2-N NaCl | 19.00 | 26.35 | 29.25 | 28.6 |
| 3-N NaCl | 18.75 | 26.53 | 30.48 | 29.85 |

It is seen that at the different periods and especially at 1:00 P. M. when the maximum temperature was attained, the temperature rise increases with the increase in density. At this latter period the differ-

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ence between the pure water and the highest concentration is 5.53°.

Experiment 5. In this experiment an attempt was made to study the influence of the salt solutions on the rise of temperature under practical conditions. The experiment was performed by inserting into the ground mercury thermometers to a depth of three inches, and 12 inches apart, and placing over an equal area, around each thermometer, equal quantities of water and some kind of salt solution. The general trend of the different tests is well illustrated by the experiment below in which NaCl and $H_2O$ were used. Exactly 500 cc. of each was poured around each thermometer. The solution was prepared by dissolving 100 grams of the salt in one liter of water.

TABLE 83.—EFFECT OF SOLUBLE SALTS ON THE RISE OF SOIL TEMPERATURE.

| Name of solution. | 10:00 a. m. | 1:50 p m. | 3:10 p. m. | 5:45 p. m. |
|---|---|---|---|---|
| $H_2O$ | 68.5°F | 75.5°F | 76.7°F | 76.0°F |
| NaCl | 68.5 | 81.5 | 83.4 | 80.8 |

It is evident that as in the preceding experiments with sand, the salt solution has a predominate influence on the rise of temperature. It will be seen that at 3:10 when the maximum temperature was attained for the day the soil treated with the salt solution is 6.70° F. warmer than the soil treated with pure water.

That the concentration of solution influences the rising of temperature and that this degree of rising may be considerable is beyond any doubt from the foregoing work. The question now is what factor or factors bring about this result. From all evidence it appears to be due to the diminution of evaporation of water by the higher surface tension and lower vapor tension of the higher densities. If this be so then the sand treated with the most concentrated solutions should contain at the end of a certain period or at the time when the maximum temperature is attained, a higher percentage of moisture than the sand to which was added pure water or dilute solutions. The determination of the moisture content of some of the lots of sand shows such to be the case. These moisture tests were made by pouring all the sand contained in the box into a large pan thoroughly mixing it and taking composite sample from the mass. The results obtained are given herewith:

TABLE 84.—MOISTURE CONTENT AT END OF EXPERIMENT.

| Name of solution. | Per cent moisture. |
|---|---|
| $H_2O$ | 2.30 |
| $KH_2PO_4$ | 3.25 |
| $K_2CO_3$ | 4.7 |
| $K_2SO_4$ | 4.0 |

It will be seen that the moisture content is higher in the sand treated with the salt than with pure water, hence it supports the hypothesis.

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The interesting question that arises now is: Is the influence of the density of the salt solutions permanent or temporary? In other words, will the temperature of the sand or soil treated with the salt solutions always continue to be higher than that of the sand or soils treated with water? For the answer of this question the experiment below was conducted. It consisted in treating sand with normal solutions of $KH_2PO_4$, KCL, and $NaNO_3$, and studying the temperature for a number of days. The data obtained are presented in the following table:

TABLE 85.—EFFECT OF SOLUBLE SALTS ON THE RISE OF SOIL TEMPERATURE.

| Name of solution. | First day. | | Second day. | | Third day. | | Fourth day. | |
|---|---|---|---|---|---|---|---|---|
| | 8:45 a. m. | 12 m. | 7:00 a. m. | 1:15 p. m. | 8:00 a. m. | 1:30 p. m. | 8:00 a. m. | 2:00 p. m. |
| $H_2O$ | 24.15°C | 27.9 °C | 17.2 °C | 29.35°C | 22.8 °C | 39.95°C | 22 0 °C | 39.4°C |
| $KH_2PO_4$ | 24.0 | 29.5 | 17.5 | 30.15 | 22.25 | 37.60 | 22.10 | 37.5 |
| KCl | 23.85 | 30.7 | 17.6 | 31.35 | 22.65 | 39.75 | 22.45 | 38.2 |
| $NaNO_3$ | 23.80 | 31.55 | 17.65 | 32.25 | 22.8 | 38.7 | 22.7 | 37.7 |

These results show that on the first day the temperature of the sand treated with the salt solution is considerably higher than that of the sand treated with pure water but the differences decrease in each succeeding day until the third day they not only disappear but the previous order is reversed: the sand treated with water has a higher temperature than the sand treated with the salt solutions.

The same order of results were also obtained with the soil: after the first day the temperature of both series was about the same.

This reversed order of the results may be explained again on the basis of the moisture content. The percentage of moisture of the sand differently treated was determined at the end of the third day with the following results:

TABLE 86.—MOISTURE CONTENT AT END OF EXPERIMENT.

| Name of solution. | Per cent moisture. |
|---|---|
| $H_2O$ | .82 |
| $KH_2PO_4$ | 1.16 |
| KCl | 1.67 |
| $NaNO_3$ | 1.90 |

It is seen that even now the moisture content of the sand treated with the salt solutions is much higher than that of the sand treated with pure water, but in both cases the amounts are quite low. Now it is conceived that in the sand treated with water, there is very little evaporation going on because the moisture present is reduced almost to the hygroscopic state, while in the sand treated with the salt solutions there is some evaporation going on because the moisture content is still con-

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siderable. The result is that the temperature of the former is raised above that of the latter.

In humid regions the effect of density of the soil solution upon the diminution of evaporation and hence upon the rising of temperature, is probably not very large but in the air dry regions—in the alkaline lands —it must be very considerable.

The interesting question that arises now is, is the temperature of the leaves of plants grown in different densities of solution any different. The writer[19] has shown that the density of the plant cell sap increased with the increase in concentration of the solution in which the plants grew and that the relative transpiration or the number of grams of water transpired to produce one gram of dry matter decreased, above a certain point, with the increase in concentration of the solution. In the light of all these facts the conclusion is irresistable that the leaves of plants grown in solutions of high concentration must have a higher temperature during the summer than the leaves of plants grown in solution of low concentration. In the winter however, the former leaves will have a lower freezing point than the latter leaves.

## LOWERING OF TEMPERATURE.

The effect of salt solutions upon the cooling or lowering of temperature of soils was studied in the same manner as the foregoing with few exceptions. The chief differences being that the present study was conducted in winter when the air temperature was very low, the thermometers used were differently constructed, and that in some cases earthenware jars 3 inches high and 3 inches in diameter were used instead of the wooden boxes. The extent and nature of the work will be revealed in the description and discussion of the following experiments:

Experiment 1. This experiment consisted in studying the effect of different concentrations of KCl and $NH_4Cl$ upon the rate of cooling and the degree of lowering of the freezing point and also upon the rate of thawing and rising of temperature. The experiment was prepared by placing 1546 grams of quartz sand in the earthenware jars and adding to the sand 300 cc of solutions of 0.0, 0.5, 1.0 and 1.5 normal of KCl and $NH_4Cl$; then placing the vessels containing the sand outdoors upon a stand during a cold night and taking records of the rate of falling of temperature every 10 minutes with thermometers graduated to 0.2° F., until the temperature of the sand in all the pots was about the same as the air temperature. The next morning when the air temperature began to rise, the jars were brought into the laboratory, whose temperature remained quite constant along 65° F., and the rate of thawing and rising of temperature was studied by taking records every 10 minutes until the sand in all the different pots was about the same and close to the room temperature. The data obtained in this experiment are shown in the tables below with their accompanied charts:

[19] Bouyoucos, G. J. Transpiration of wheat seedlings as affected by different densities of a complete nutrient solution in water, sand and soil cultures.
Beihefte zum Botanischen Centralblatt.
Heft 1, November, 1912.

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TABLE 87,—EFFECT OF SALT SOLUTIONS ON THE RATE OF FREEZING AND THE DEGREE OF THE LOWERING OF THE FREEZING POINT.

| Time, | P. M. 3:55 | 4:05 | 4:15 | 4:25 | 4:35 | 4:45 | 4:55 | 5:05 | 5:15 | 5:25 | 5:35 | 5:45 | 5:55 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 61.9 | 54.2 | 49.7 | 44.8 | 41.0 | 36.6 | 34.0 | 32.4 | 32.0 | 31.8 | 31.8 | 31.8 | 31.8 |
| 0.5n.KCl | 61.7 | 54.0 | 49.8 | 44.9 | 41.1 | 36.9 | 33.3 | 30.0 | 28.6 | 28.8 | 28.8 | 28.8 | 28.8 |
| 1.0n KCl | 61.4 | 53.8 | 49.4 | 44.7 | 40.9 | 36.5 | 33.0 | 29.6 | 26.8 | 25.2 | 23.4 | 25.6 | 25.6 |
| 1.5n.KCl | 61.8 | 54.2 | 49.7 | 44.8 | 41.0 | 36.6 | 33.0 | 29.6 | 26.8 | 25.0 | 23.2 | 21.6 | 20.4 |
| 0.5n.$NH_4Cl$ | 62.5 | 54.2 | 49.7 | 44.9 | 41.0 | 36.7 | 33.0 | 29.8 | 28.0 | 28.4 | 28.4 | 28.4 | 28.4 |
| 1.0n.$NH_4Cl$ | 62.0 | 54.6 | 50.3 | 45.6 | 41.7 | 37.7 | 33.6 | 30.6 | 27.8 | 26.0 | 24.4 | 25.0 | 25.0 |
| 1.5n.$NH_4Cl$ | 62.2 | 54.8 | 50.4 | 45.6 | 41.7 | 37.5 | 33.5 | 30.2 | 27.4 | 25.6 | 24.0 | 22.6 | 22.0 |
| Air | 20.5 | 19.5 | 19.0 | 18.0 | 16.5 | 13.5 | 13.5 | 13.0 | 13.0 | 12.5 | 12.5 | 12.0 | 12.0 |

| Time. | P. M. 6:05 | 6:15 | 6:25 | 6:35 | 6:45 | 6:55 | 7:05 | 7:15 | 7:25 | 7:35 | 7:45 | 7:55 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 31.8 | 31.8 | 31.8 | 31.8 | 31.8 | 31.8 | 31.8 | 31.8 | 31.6 | 31.4 | 30.9 | 30.0 |
| 0.5n.KCl | 28.6 | 28.6 | 28.4 | 28.2 | 27.8 | 27.5 | 27.2 | 26.8 | 26.4 | 25.8 | 25.4 | 25.0 |
| 1.0n.KCl | 25.6 | 25.4 | 25.2 | 25.0 | 24.5 | 24.1 | 23.6 | 23.4 | 23.0 | 22.6 | 22.4 | 22.0 |
| 1.5n.KCl | 19 2 | 20.6 | 20.8 | 20.8 | 20.6 | 20.4 | 20.1 | 19.9 | 19.6 | 19.4 | 19.2 | 19.0 |
| 0.5n$NH_4Cl$ | 28.2 | 28.2 | 28.2 | 28.2 | 27.6 | 27.6 | 27.1 | 26.6 | 25.8 | 25.0 | 24.4 | 23.6 |
| 0.0n.$NH_4Cl$ | 25.0 | 25.0 | 25.0 | 25.0 | 24.8 | 24.4 | 24.1 | 24.0 | 23.6 | 23.4 | 23.0 | 22.8 |
| 1.5n.$NH_4Cl$ | 22.0 | 22.0 | 22 0 | 22.0 | 21.8 | 21.6 | 21.4 | 21.2 | 21.0 | 20.6 | 20.4 | 20.2 |
| Air | 11.7 | 11.5 | 11.5 | 11.5 | 11.3 | 11.3 | 11.3 | 11.2 | 12.0 | 12.2 | 12.5 | 12.2 |

| Time. | P. M. 8:05 | 8:15 | 8:25 | 8:35 | 8:45 | 8:55 | 9:05 | 9:15 | 9:25 | 9:35 | 9:45 | 9:55 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 29.2 | 28.1 | 26.8 | 25.0 | 23.6 | 22.4 | 21.8 | 21.4 | 20.7 | 20.0 | 19.4 | 18.9 |
| 0.5n.KCl | 24.6 | 24.4 | 24.0 | 23.6 | 23.2 | 23.0 | 22.6 | 22.2 | 21.9 | 21.6 | 21.2 | 20.8 |
| 1.0n.KCl | 21.8 | 21.5 | 21.2 | 21.0 | 20.8 | 20.6 | 20.4 | 20.2 | 20.0 | 19.8 | 19.6 | 19.4 |
| 1.5n.KCl | 18 8 | 18.7 | 18.6 | 18.4 | 18.4 | 18.2 | 18.2 | 18.1 | 18.0 | 17.9 | 17.8 | 17.7 |
| 0.5n.$NH_4Cl$ | 23.2 | 22.6 | 22.2 | 21.6 | 21.2 | 20.7 | 20.2 | 19.8 | 19.4 | 19.0 | 18.6 | 18.4 |
| 1.0n$NH_4Cl$ | 22.6 | 22.4 | 22.2 | 22.0 | 21.8 | 21.6 | 21.4 | 21.2 | 21.0 | 21.0 | 20.8 | 20.5 |
| 1.5n.$NH_4Cl$ | 20.0 | 19.8 | 19.8 | 19.6 | 19.4 | 19.4 | 19.2 | 19.0 | 19.0 | 18.8 | 18.7 | 18.6 |
| Air | 13.5 | 12.4 | 13.0 | 12.5 | 12.0 | 13.0 | 14.0 | 14.0 | 13.0 | 12.5 | 14.0 | 14.0 |

| Time. | P. M. 10:05 | 10:15 | 10:25 | 10:35 | 10:45 | 10:55 | 11:05 | 11:15 | 11:25 | 11:35 | 11:45 | 11:55 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 18.5 | 18.2 | 17.7 | 17.3 | 16.8 | 16.4 | 16.2 | 15.9 | 15.8 | 15.6 | 15.6 | 15.6 |
| 0.5n.KCl | 20.6 | 20.2 | 19.9 | 19.6 | 19.2 | 18.9 | 18.4 | 18.2 | 18.0 | 17.8 | 17.6 | 17.4 |
| 1.0n.KCl | 19.2 | 19 0 | 18.9 | 18.8 | 18.5 | 18.3 | 18.0 | 17.8 | 17.6 | 17.5 | 17.4 | 17.3 |
| 1.5n.KCl | 17.6 | 17.6 | 17.5 | 17.4 | 17.3 | 17.2 | 17.0 | 16.9 | 16.8 | 16.8 | 16.7 | 16.6 |
| 0.5n.$NH_4Cl$ | 18.2 | 17.8 | 17.6 | 17.3 | 17.0 | 16.8 | 16.4 | 16.2 | 16.2 | 16.0 | 15.9 | 15.8 |
| 1.0n.$NH_4Cl$ | 20.4 | 20.2 | 20.0 | 19.8 | 19.6 | 19.4 | 19.2 | 19.0 | 18.8 | 18.6 | 18.5 | 18.4 |
| 1.5n.N,$H_4Cl$ | 18.5 | 18.4 | 18.3 | 18.2 | 18.0 | 17.9 | 17.8 | 17.6 | 17.6 | 17.4 | 17.4 | 17.2 |
| Air | 14.3 | 13.5 | 14 2 | 13.0 | 13.0 | 13.0 | 13.8 | 14.0 | 13.8 | 14.0 | 14.2 | 14.0 |

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TABLE 88.—EFFECT OF SALT SOLUTIONS ON THE RATE OF THAWING AND THE DEGREE OF THE RISING OF TEMPERATURE.

| Time. | A. M. 8:00 | 8:10 | 8:20 | 8:30 | 8:40 | 8:50 | 9:00 | 9:10 | 9:20 | 9:30 | 9:40 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 1.2 | 10.0 | 15.0 | 20.3 | 24.4 | 27.0 | 29.8 | 30.6 | 31.2 | 31.3 | 31.4 |
| 0.5n.KCl | 2.9 | 9.6 | 11.2 | 11.8 | 13.8 | 17.0 | 19.6 | 21.2 | 22.7 | 23.6 | 24.6 |
| 1.0n.KCl | 3.4 | 10.0 | 11.2 | 11.8 | 12.0 | 12.1 | 12.6 | 15.0 | 17.8 | 19.0 | 20.4 |
| 1.5n.KCl | 3.4 | 5.6 | 11.2 | 11.6 | 11.8 | 11.9 | 12.0 | 12.1 | 12.4 | 12.8 | 14.8 |
| 0.5n.$NH_4Cl$ | 2.8 | 8.6 | 12.1 | 15.8 | 18.6 | 20.4 | 22.0 | 23 2 | 24.3 | 25.0 | 25 7 |
| 1.0n.$NH_4Cl$ | 3.3 | 5.6 | 8.9 | 12.1 | 14.6 | 16.3 | 18.0 | 19.2 | 20.4 | 21.2 | 22.0 |
| 1.5n.$NH_4Cl$ | 3.2 | 4.2 | 6.1 | 9.5 | 11.2 | 14.0 | 15.8 | 17.0 | 17.4 | 19.2 | 20.3 |
| Air | 63. | 63.0 | 63.5 | 63.5 | 64.0 | 64.0 | 64.5 | 64.5 | 65.0 | 65.0 | 65.3 |

| Time. | A. M. 9:50 | 10:00 | 10:10 | 10:20 | 10:30 | 10:40 | 10:50 | 11:00 | 11:10 | 11:20 | 11:30 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 31.5 | 31.6 | 31.6 | 31.7 | 31.7 | 31.8 | 31.8 | 31.8 | 31.8 | 31.8 | 31.8 |
| 0.5n.KCl | 25.2 | 25.7 | 26.3 | 26.6 | 26.9 | 27.2 | 27.5 | 27.8 | 28.1 | 28.4 | 29.0 |
| 1.0n.KCl | 21.3 | 22.0 | 22.6 | 23.0 | 23.8 | 24.3 | 25.0 | 26.0 | 27.2 | 31.4 | 34.2 |
| 1.5n.KCl | 17.0 | 18.2 | 19.3 | 21.1 | 23.4 | 25.2 | 28.9 | 32.2 | 34.8 | 37.2 | 39.4 |
| 0.5n.$NH_4Cl$ | 26.2 | 26 6 | 26.9 | 27.2 | 27.5 | 27.8 | 28.1 | 28.5 | 29.5 | 31.3 | 33.6 |
| 1.0n.$NH_4Cl$ | 22.6 | 23.2 | 23.7 | 24.0 | 24.6 | 25.0 | 25.7 | 27.2 | 29.2 | 32.4 | 34.6 |
| 1.5n.$NH_4Cl$ | 21.0 | 21.8 | 23.0 | 25.2 | 28.5 | 31.4 | 34.8 | 36.3 | 38.3 | 40.5 | 42.2 |
| Air | 66.5 | 66.5 | 66.8 | 67.0 | 67.5 | 68.5 | 68.5 | 68.5 | 68.5 | 69.0 | 69.0 |

| Time. | A. M. 11:40 | 11:50 | M. 12:00 | P. M. 12 :10 | 12:20 | 12:30 | 12:40 | 12:50 | 1:00 | 1:10 | 1:20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 31.8 | 32.0 | 32.1 | 32.1 | 32.2 | 33.0 | 34.6 | 37.2 | 40.5 | 43.6 | 46.1 |
| 0.5n.KCl | 30.0 | 33.4 | 36.1 | 38.5 | 40.5 | 42.2 | 44.0 | 45.6 | 47.2 | 48.7 | 50.3 |
| 1.0n.KCl | 35.8 | 38.7 | 40.5 | 42.7 | 44.1 | 45.5 | 47.0 | 48.2 | 49.6 | 50.9 | 52.3 |
| 1.5n.KCl | 40.8 | 43.2 | 44.7 | 46.1 | 47.4 | 48.5 | 49.6 | 50.6 | 51.7 | 52.8 | 53.8 |
| 0.5n.$NH_4Cl$ | 33.8 | 40.9 | 43.0 | 44.2 | 46.4 | 47.8 | 49.2 | 50.4 | 51.6 | 52.8 | 54.1 |
| 1.0n.$NH_4Cl$ | 36.4 | 39.1 | 41.0 | 42.8 | 44.4 | 45.7 | 47.1 | 48.4 | 50.5 | 51.0 | 52.2 |
| 1.5n.$NH_4Cl$ | 43.4 | 45.4 | 46.6 | 47.9 | 49.0 | 49.8 | 50.8 | 51.6 | 52.6 | 53.6 | 54.6 |
| Air | 69.0 | 67.8 | 67.0 | 68.0 | 68.5 | 67.5 | 69.5 | 69.5 | 70.0 | 69.0 | 69.0 |

| Time. | P. M. 1:30 | 1:40 | 1:50 | 2:00 | 2:10 | 2:20 | 2:30 | 2:40 | 2:50 | 3:00 |
|---|---|---|---|---|---|---|---|---|---|---|
| $H_2O$ | 47.4 | 49.2 | 50.8 | 52.2 | 53.8 | 54.5 | 55.4 | 56.3 | 57.3 | 58.0 |
| 0.5n.KCl | 51.1 | 52.3 | 53.5 | 54.4 | 55.2 | 55.9 | 56.6 | 57.3 | 57.8 | 58.5 |
| 1.0n.KCl | 53.0 | 54.0 | 55.0 | 55.8 | 56.5 | 57.0 | 57.8 | 58.3 | 58.9 | 59.4 |
| 1.5n.KCl | 54.4 | 55.2 | 56 0 | 56.6 | 57.5 | 57.8 | 58.4 | 58.8 | 59.3 | 59.8 |
| 0.5n.$NH_4Cl$ | 54.7 | 55.7 | 56.6 | 57.3 | 58.0 | 58.5 | 59.1 | 59.6 | 60.1 | 60.6 |
| 1.0n.$NH_4Cl$ | 52.9 | 54.0 | 55.0 | 55.6 | 56.2 | 57.0 | 57.6 | 58.2 | 58.7 | 59.2 |
| 1.5n.$NH_4Cl$ | 55.0 | 55.6 | 56.5 | 57.2 | 57.8 | 58.2 | 58.8 | 59.2 | 59.6 | 60.1 |
| Air | 69.0 | 68.5 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 | 70.0 |

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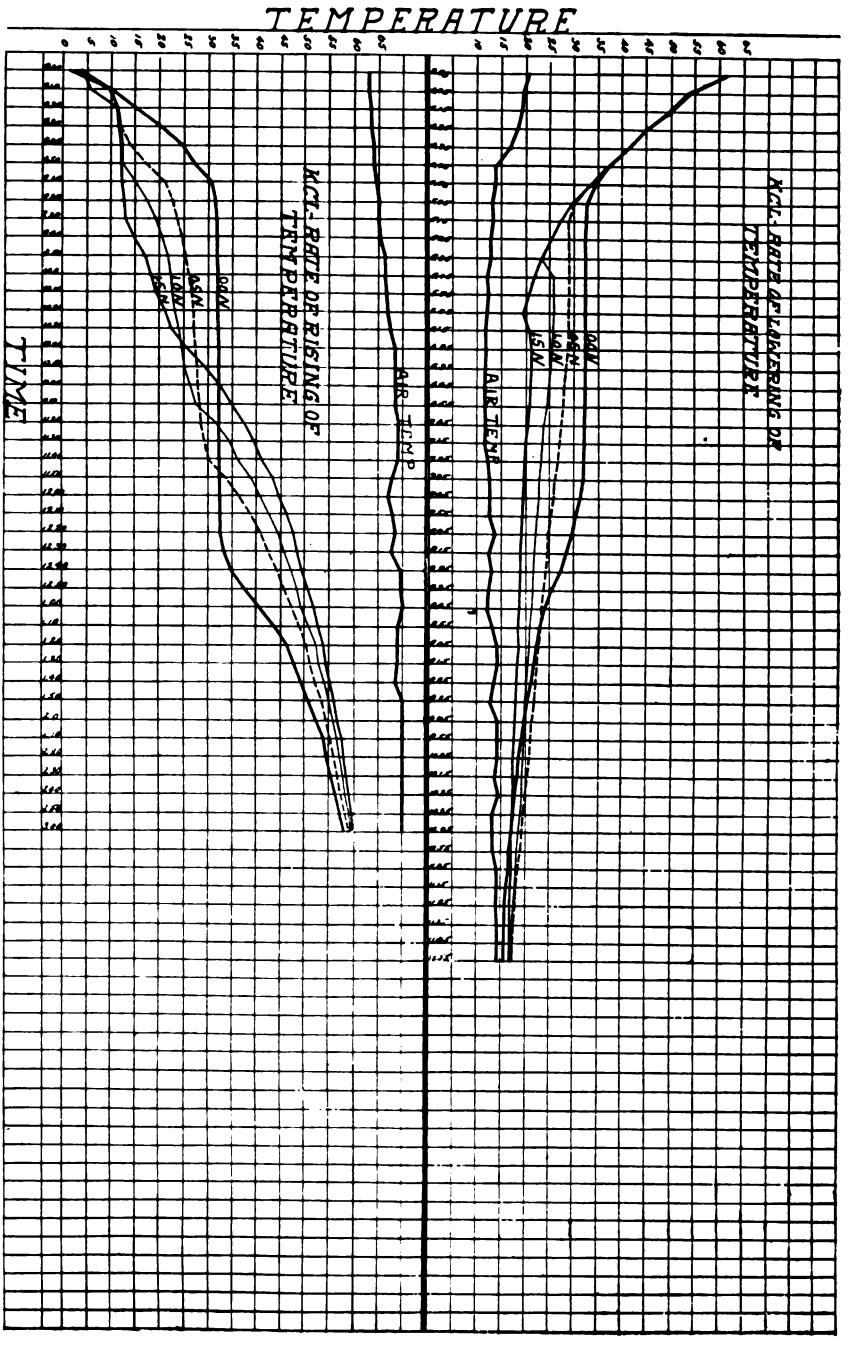


FIG. 52.

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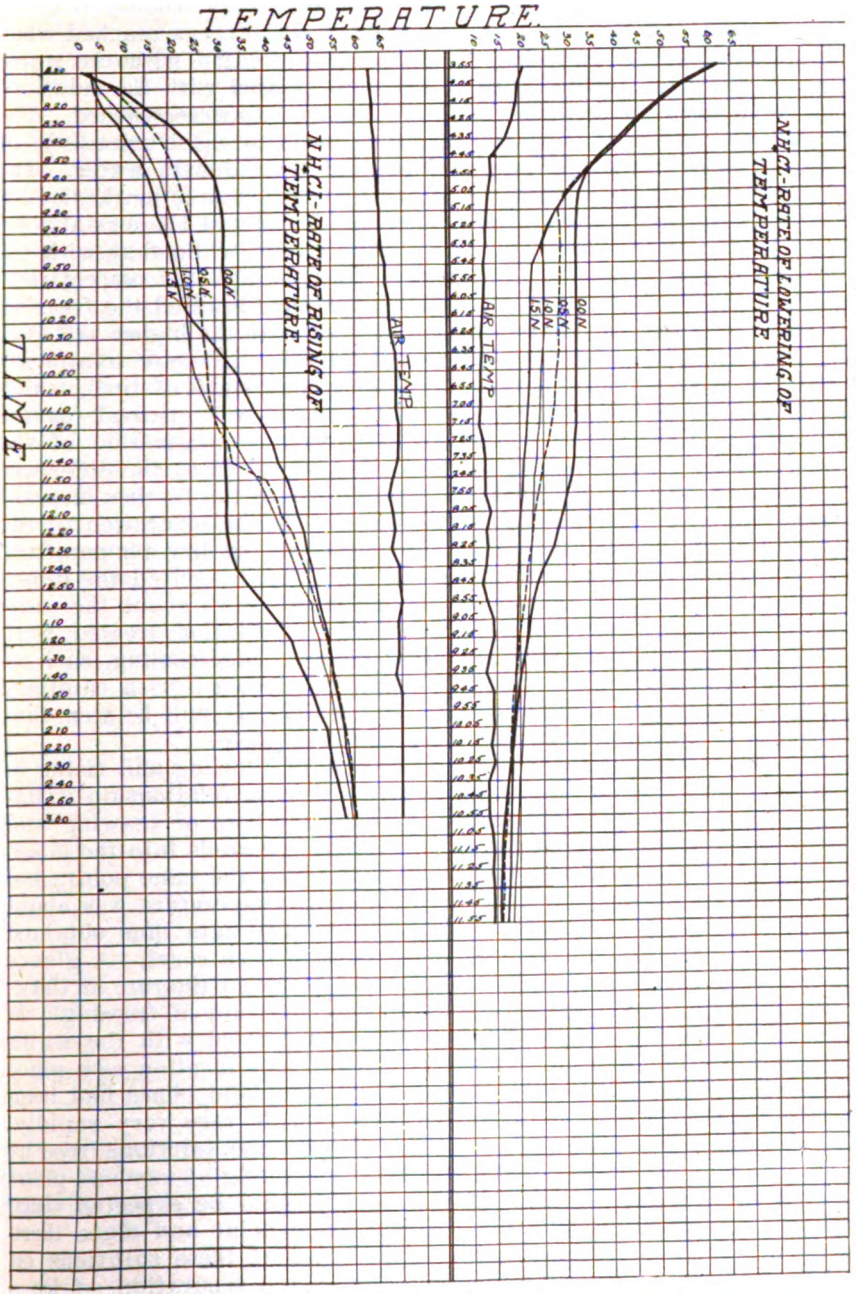


FIG. 53.

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The foregoing tables and charts show many extremely interesting facts. Considering first the rate of freezing it will be seen that the sand treated with the different solutions and with pure water cooled at about the same rate until the temperature of about 34° F. was reached when the rate of falling of temperature of the sand treated with the water slowed up while the temperature of the sand treated with the solutions continued to fall until the respective freezing points were reached. The sand, therefore, treated with the solutions came to the temperature of 32° F. about 15 minutes before did the sand treated with water. The freezing point of the sand with the different treatments is markedly different; that with water is 31.8°., that with 0.5, 1.0 and 1.5 normal solutions of KCl is 28.8°, 25.6° and 20.8° respectively, while that with 0.5 1.0 and 1.5 normal solutions of $NH_4Cl$ is 28.4, 25, and 22° respectively. From these figures it is evident that the salts have lowered the freezing point and the degree of this lowering is greater with the higher salt content present. After the temperature of all the different treatments reached the freezing it remained there for some length of time, which amount of time varied with the concentration: it was greatest for the pure water and decreased with the increase in concentration of the solution. This is an interesting fact and it is explained by the difference in the further lowering of the freezing point due to the further increase in concentration of the solution brought about by the separation of the solidified solvent or ice under the subjection of the low temperature. Finally, however, the temperature of the sand which received the different densities of solution as well as the water, came to about the same point, with a slight difference in favor of the solution treated with sand. It is to be noted that the phenomenon of supercooling, such as observed in the freezing of water in the form of drops or in capillary tubes, also occurred in the freezing of soil water. It will be seen that in almost every case some supercooling did take place.

It will be interesting now to study the rate of thawing and rising of temperature of the same lot of sands and see what relationship it has to the rate of freezing. As already stated, this rate of thawing and rising of temperature was measured by bringing the sands into the laboratory after their temperature was lowered to about the same point, and records were taken every 10 minutes until their temperature was about the same and close to the room temperature. The data thus obtained are shown in table 88, and on the lower part of each chart. A glance at these results reveals at once the significant fact that the rate of thawing was in every case, exactly the reverse of the rate of freezing. It will be seen that the temperature of the sand treated with the water rose at once to 31.8° F. or at the point in which solidification took place and remained there for a long time until all the solid phase had been converted over into the liquid phase and then it rose very rapidly. While the temperature of the sand treated with the solutions rose at the beginning slowly and gradually without remaining at any one point for any length of time—which is just what should be expected since fusion and solidification take place at the same point and since there were more than one freezing point in the case of these solutions on account of their further concentration due to the separation of ice—until complete fusion had taken place and then it rose very rapidly and far above that of the sand treated with water. The rapidity with

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which complete fusion took place and the temperature passed the 32° F. point was proportional to the concentration of the treatment. It will be noticed that by the time the temperature of the sand treated with water began to rise above 32° F., the degree of magnitude of the temperature of the other lots of sand varied directly with the density of the solution. In the case of the KCl experiment for instance, the difference in temperature between the sand treated with water and that treated with 1.5 normal solution was as great as 17° F. Finally, however, all the differently treated sands attained about the same temperature. The differences noted increase with the decrease in concentration of the solution and would necessarily exist on account of the difference in evaporation.

Experiment 2. This experiment was an extension and check to the foregoing experiment. It consisted in studying the effect of 0.0, 0.5, 1.0 and 1.5 normal solutions of NaCl and KCl and 1.0 normal solutions of $K_2CO_3$, $NaNO_3$, $CaCl_2$ $KNO_3$, and $(NH_4)_2CO_3$ upon the rate of freezing, the degree of the lowering of the freezing point, and the rate of the rising of temperature. It was prepared by placing 6855 grams of quartz sand in the regular wooden boxes, added 750 cc of the respective solutions, and the temperature records were taken in the usual manner. In the table below is given only the lowering of the freezing point, the rate of freezing and of thawing are left out on account of lack of space; the general trend of these, however, is well illustrated in the foregoing experiment.

TABLE 89.—FREEZING POINT OF SOLUTIONS IN SAND.

| Name of solution. | Freezing point. |
|---|---|
| Water | 31.8 |
| 0.5 N. NaCl | 28.8 |
| 1.0 N. NaCl | 25.4 |
| 1.5 N. NaCl | 22.2 |
| 0.5 N. KCl | 29.0 |
| 1.0 N. KCl | 25.6 |
| 1.5 N. KCl | 23 0 |
| 1.0 N. $K_2CO_3$ | 28. |
| 1.0 N. $KNO_3$ | 26. |
| 1.0 N. $CaCl_2$ | 27. |
| 1.0 N. $(NH_4)_2CO_3$ | 28.2 |

It will be seen that the lowering of the freezing increased with the concentration and that it varied but slightly among the different salt solutions of the same strength.



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## EFFECT OF THE DECOMPOSITION OF MANURE ON SOIL TEMPERATURE.

### OBJECT AND METHOD OF EXPERIMENTATION.

It might be said that the farm soil receives its heat from four different sources: (1) from the direct radiation of the sun; (2) from the precipitation or condensation of aqueous vapor, (3) from the heated interior of the earth by conduction, and (4) from the decomposition of organic matter. The amount received from the last three sources is very small; it is the first source that contributes the greatest, if not the whole, of the warmth of the soil. The second and third sources are entirely beyond the control of man; the first can be controlled in an indirect way by modifying the color and water content of the surface soil; the fourth is the only one of the four sources which is practically entirely under the control of man, because he can add the organic matter to the soil.

The amount of heat liberated by the decomposition of organic matter is considerable if the action is complete and rapid—it is equal to the amount of heat of combustion. The decomposition process, however, as carried on under field conditions is very slow and hence the amount of heat given off is practically imperceptible.

The principal sources of organic matter in the soil are (1) vegetable matter and (2) animal manure. The first is practically unimportant so far as heat is concerned because in the spring the temperature of the soil is already sufficiently high enough for the germination of seed and growth of plants by the time the vegetation has grown large enough to be turned under. In the fall the soil temperature is also sufficiently high for the germination of seeds and growth of seedlings without the necessity of increasing it. Furthermore, at either season the amount of vegetation that can be turned under is so small in comparison with the great bulk of the soil that the warming effect resulting from the decomposition is practically nil.

The extent to which the second source of organic matter may increase the temperature of the soil will depend upon the freshness and quantity of the material. The statements in different textbooks vary upon this point. Some are to the effect that the decomposition of manure of any kind has practically no importance on the thermal relations of soils; others, that the influence is quite appreciable.

These statements or conclusions have been drawn from insufficient data. The amount of experimentation that has already been done on the subject is very meager. The most widely quoted work is that of Georgeson[20] who added 0.0, 10, 20, 40 and 80 tons of farm yard manure to a soil and studied its temperature. The experiment was performed by mixing thoroughly the soil and the manure, placing the mixture in wooden boxes without bottom and top and burying the latter in the ground up to the surface edge. He found that the temperature of the soil was increased with the increase of the application of manure. The

[20] Agricultural Science 1:251.

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increase was greatest during the first five days and then rapidly diminished. At the end of 20 days the increase became almost imperceptible where only 10 tons of manure per acre had been applied but continued to be distinct where 40 and 80 tons were employed.

Wagner[21] conducted a somewhat similar field experiment with different kinds of manure and also some laboratory experiments. The field tests showed that the application of heavy dressings of fresh manure of horse, cow, sheep and hog, raised the temperature of the soil; the horse manure increased it the most, the cow the least, and the sheep and hog intermediately.

Spragg[22] attempted to study the effect of farm yard manure of horse, sheep, and cow under laboratory and field conditions. The data he obtained show that the rise of temperature as a result of these applications is practically nil.

Since our knowledge of this subject was very meager and since the foregoing works as well as the statements found in various textbooks are not concordant, it was deemed advisable to investigate the subject.

The research consisted in studying the effect of the decomposition of different kinds of fresh manure upon the temperature of soils, under laboratory or controlled conditions. The investigation was conducted in the following manner: Four-gallon earthenware jars were insulated on the inside with thick asbestos paper and on the outside with thick hair felt. The asbestos on the inside of the jars was paraffined in order to make it water proof. The reason for so insulating the jars was to prevent the loss of heat by conduction from the sides and bottom and thus imitate in a way natural conditions. In actual field conditions, the loss of heat takes place from the surface soil. To each pot was then added the same amount of a fine sandy soil, known as Jack pine sand. From each jar was then taken equal weights of soil to correspond to a depth of 6 inches. This soil was thoroughly mixed with the proper amount and kind of manure and put back into the pot, and water added to it to bring it to the required moisture content. Care was taken to have the same percentage of moisture in the soils containing different amounts of the same kind of manure. This, of course, necessitated the making of corrections for the different amounts of water contained in the various proportions of manure. The correction was made only within the various amounts of the same kind of manure and not among the different kinds. The soils, therefore, containing the different kinds of manure in the various proportions did not possess exactly the same moisture content. In order to prevent evaporation as much as possible the surface soil of each pot was also covered by a thick layer of quartz sand.

There were four experiments conducted. The first three dealt only with horse manure and the fourth with horse, sheep, and cow manure. Since the first three experiments were preliminary and the results obtained are in the same order as the corresponding series in the fourth experiment; also, for the sake of brevity, only the results of the latter will be presented here.

The three different kinds of manure, horse, sheep, and cow, were only

[21] Forsch. a. d. G. d. Agrik. Phy. V. : 373.
[22] Thesis. 1906. Mich. Agr. Coll.

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about one day old when they were added to the soil. For convenience and comparison only the pure solid was used. They were employed in the proportion of 0.0, 5, 10, 20, and 40 tons per acre, and 100% of cow and horse. Their moisture content was determined and shown in the table below. It will be seen that their water content is different. No correction was made for these differences in the weight of the manure added to the soil, consequently the actual amount of dry matter was not the same. Since the moisture consists of urine and this undergoes fermentation, it also adds heat to the soil.

The preparation of the experiment including, the weight of the soil, name and amount of manure added, the moisture content, etc., are all shown together in the following table:

TABLE 90.—SHOWING PLAN OF EXPERIMENT.

| Weight of soil. | Tons manure per acre. | Moisture of manure. | Percent moisture H. M. Expt. | Per cent moisture C. M. Expt. | Per cent moisture S. M. Expt. |
|---|---|---|---|---|---|
| 396 lbs. | 0.0 | Horse | 17.39 | 17.52 | 17.42 |
| 396 lbs. | 5.0 | 84.05 | 17.39 | 17.52 | 17.42 |
| 396 lbs. | 10.0 | Cow | 17.39 | 17.52 | 17.42 |
| 396 lbs. | 20.0 | 84.00 | 17.39 | 17.52 | 17.42 |
| 396 lbs. | 30.0 | Sheep | 17.39 | 17.52 | 17.42 |
| 396 lbs. | 40.0 | 75.50 | 17.39 | 17.52 | 17.42 |

6 Kilos horse manure.
6 Kilos cow manure.

When the preparation of the experiment was complete the pots were placed in rows on a stand one foot from the ground and kept in a room whose temperature varied very little from day to day. The room was intended for refrigerating purposes and was ideal for keeping the temperature constant.

In the first three experiments the temperature readings were taken by means of mercury thermometers graduated to 1° Centigrade. The results obtained by them were not altogether satisfactory because they did not read closely enough. To obtain mercury thermometers of high precision and the large number required in the present extensive work, it would have entailed considerable expense. To overcome this difficulty, it was decided to use thermocouples in the present or fourth experiment. The principle of such instruments is based upon the fact that when two wires of dissimilar metals are connected end to end and one junction is kept at a constant and the other at a variable temperature, an electrical current is produced the amount of which is proportional to the difference in temperature between the two junctions. This electrical current is measured by the deflection produced on the galvanometer. The amount of electrical current is also influenced by the composition of the wires. The combination of certain kinds of elements produces a greater current than others.

The thermocouples used in the present work were made in this laboratory especially for the purpose. Their material consisted of No. 18 "advance" wire and No. 18 copper wire. They were constructed by

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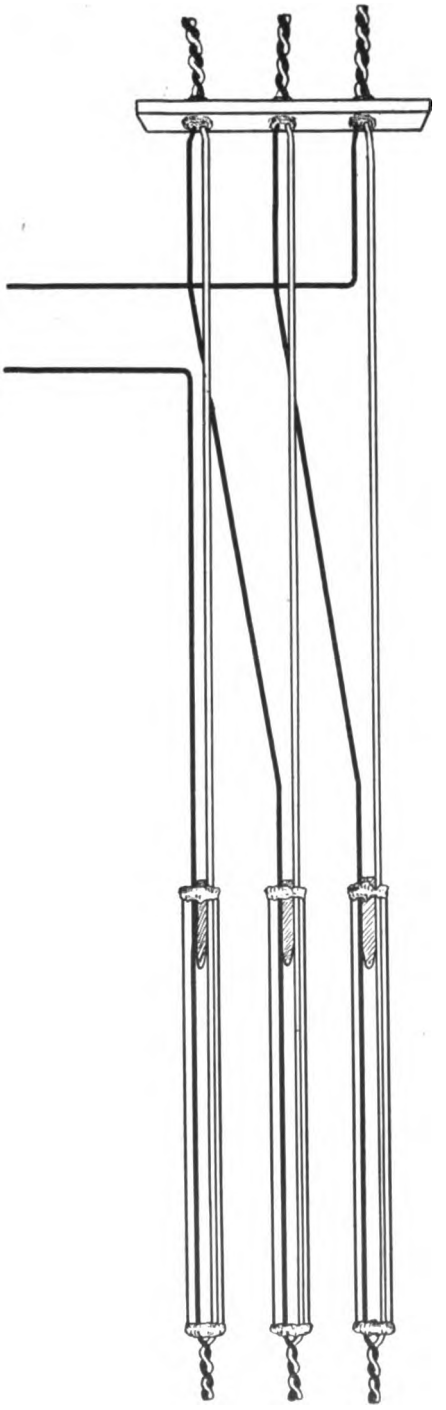

FIG. 54.

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taking 25″ pieces of the respective wires and joining them in series of three. That is, three couples were joined together in series. The joints were first dipped in ZnCL, then soldered and finally coated with shellac. Above the joints, which were to be buried in the soil, were placed glass tubes 6 inches long and $\frac{1}{8}$ inch in diameter. The opposite ends of these glass tubes were made waterproof with shellac. These glass tubes were employed in order to facilitate the placing of the ends of the couples into the soil and also to keep the wires of the latter well insulated. To each series of couples were joined copper wires 12 feet long. All the couples were then standardized. This was accomplished by dipping one end of the series of couples in ice and the other in a constant temperature bath. It was found that they were all sensitive to about 0.2° C.

Those ends of the couples having the glass tubes were placed into the soil five inches deep from the lowest end of the point or four inches from the upper part of the joint. The three couples were placed at different places in the soil in order to obtain a more nearly average record. The temperature readings were made by dipping the long bended end—as shown in the diagram—into an ice bath, connecting the two 12 foot wires to the galvanometer, and reading the deflection on the latter. The galvanometer employed was of D'Arsonval type and was of very high grade. Its needle came to rest in a few seconds. It took only about 40 minutes to complete the reading of the 40 thermocouples. At the beginning of the experiment there were two readings made, one in the morning at 8:00 and one in the afternoon at 3:30. Later, however, the readings were made only in the afternoon. At the beginning also, the readings were taken every day but after the maximum temperature was attained they were taken every other day for some time and occasionally afterwards. The experiment lasted altogether from December 28th to April 10th, or 103 days. The data obtained are given herewith:

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## RESULTS OF EXPERIMENTS.

TABLE 91.—EFFECT OF DECOMPOSITION OF MANURE ON TEMPERATURE OF SOILS.

| 1911. | December 28. | | | December 29. | | | December 30. | | | December 31. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| | C° | C° | C° | C° | C° | C° | C° | C° | C° | C° | C° | C° |
| 0..... | 15.4408 | 15.4408 | 15.4408 | 14.8954 | 14.8954 | 14.8954 | 15.0227 | 15.0227 | 15.0227 | 15.3863 | 15.3863 | 15.3863 |
| Diff..... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 15.4045 | 15.3378 | 14.9985 | 15.1015 | 15.5014 | 15.2712 | 15.2742 | 15.7075 | 15.4227 | 15.6529 | 16.0387 | 15.8105 |
| Diff..... | -0.0363 | -0.1029 | -0.4423 | 0.2061 | 0.606 | 0.3758 | 0.2515 | 0.6848 | 0.4000 | 0.2666 | 0.6423 | 0.4241 |
| 10..... | 15.4348 | 15.3015 | 15.0894 | 15.2409 | 15.5439 | 15.3045 | 15.5045 | 15.7560 | 15.4530 | 15.9317 | 16.0802 | 15.8590 |
| Diff..... | -0.006 | -0.1393 | -0.3514 | 0.3455 | 0.6485 | 0.4091 | 0.4818 | 0.7333 | 0.4303 | 0.5454 | 0.6938 | 0.4726 |
| 20..... | 15.5984 | 15.4105 | 15.1803 | 15.6772 | 15.6014 | 15.4227 | 15.9832 | 15.8923 | 15.6045 | 16.3014 | 16.2377 | 15.9802 |
| Diff..... | 0.1576 | -0.0362 | -0.2665 | 0.7818 | 0.706 | 0.5273 | 0.9605 | 0.8696 | 0.5818 | 0.915 | 0.8514 | 0.5938 |
| 30..... | 15.7257 | 15.5742 | 15.5742 | 16.065 | 15.7923 | 15.6802 | 16.468 | 16.0438 | 15.8772 | 16.7498 | 16.4377 | 16.3256 |
| Diff..... | 0.2849 | 0.1334 | 0.1334 | 1.1698 | 0.8969 | 0.7848 | 1.4453 | 1.0211 | 0.8545 | 1.3635 | 1.0514 | 0.9392 |
| 40..... | 15.9681 | 15.7105 | 15.8166 | 16.7559 | 15.9529 | 15.9196 | 17.2104 | 16.2529 | 16.2044 | 17.4770 | 16.6589 | 16.6650 |
| Diff..... | 0.5273 | 0.2697 | 0.3758 | 1.8605 | 1.0575 | 1.0242 | 2.1877 | 1.2302 | 1.1817 | 2.0917 | 1.2726 | 1.2787 |
| 100%... | 37.5 | ..... | ..... | 37.2000 | 19.33 | ..... | 38.3 | 18.693 | ..... | 37.500 | 18.720 | ..... |
| Diff..... | 22.0592 | ..... | ..... | 22.3046 | 4.4346 | ..... | 23.2773 | 3.6703 | ..... | 22.1136 | 3.3336 | ..... |
| Air..... | ..... | ..... | ..... | ..... | ..... | 16.665 | ..... | ..... | 16.8771 | ..... | ..... | 17.2710 |
| Diff..... | ..... | ..... | ..... | ..... | ..... | 2.7696 | ..... | ..... | 1.8554 | ..... | ..... | 1.8847 |

TABLE 91.—Continued.

| 1912. | January 1. | | | January 2. | | | January 3. | | | January 4. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| 0..... | 15.3015 | 15.3015 | 15.3015 | 15.2106 | 15.2106 | 15.2106 | 14.8954 | 14.8954 | 14.8954 | 14.6288 | 14.6288 | 14.6288 |
| Diff..... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 15.5863 | 16.0074 | 15.6651 | 15.5499 | 15.8469 | 15.453 | 15.1621 | 15.5105 | 15.0227 | 14.8470 | 15.2106 | 14.7621 |
| Diff..... | 0.2848 | 0.7059 | 0.3636 | 0.3393 | 0.6363 | 0.2424 | 0.2666 | 0.6151 | 0.1272 | 0.2182 | 0.5817 | 0.1332 |
| 10..... | 15.859 | 15.962 | 15.7681 | 15.7620 | 15.9075 | 15.5257 | 15.3621 | 15.5136 | 15.2106 | 15.0833 | 315.2772 | 14.9379 |
| Diff..... | 0.5575 | 0.6605 | 0.4666 | 0.5514 | 0.6969 | 0.3151 | 0.4667 | 0.6181 | 0.3151 | 0.4545 | 0.6484 | 0.3090 |
| 20..... | 16.2105 | 16.1650 | 15.9014 | 16.0105 | 16.0408 | 15.6651 | 15.7135 | 15.6651 | 15.3621 | 15.3924 | 15.3863 | 15.0651 |
| Diff..... | 0.9090 | 0.8635 | 0.5999 | 0.7999 | 0.8302 | 0.4545 | 0.8181 | 0.7696 | 0.4666 | 0.7636 | 0.7575 | 0.4362 |
| 30..... | 16.6165 | 16.3347 | 16.1680 | 16.4226 | 16.2074 | 16.1317 | 16.1014 | 15.862 | 15.5863 | 15.8408 | 15.6135 | 15.3863 |
| Diff..... | 1.3150 | 1.0332 | 0.8665 | 1.212 | 0.9968 | 0.9211 | 1.2059 | 0.9665 | 0.6908 | 1.2120 | 0.9847 | 0.7574 |
| 40..... | 17.3073 | 16.5225 | 16.4468 | 17.1982 | 16.4074 | 16.3741 | 16.7437 | 16.0408 | 15.9984 | 16.4529 | 15.765 | 15.6651 |
| Diff..... | 2.0658 | 1.221 | 1.1453 | 1.9276 | 1.1968 | 1.1635 | 1.8483 | 1.1453 | 1.1030 | 1.8241 | 1.1362 | 1.0332 |
| 100%... | 37.1 | 18.666 | ..... | 34.5 | 18.666 | ..... | 31.5 | 18.61 | ..... | 30.2 | 18.166 | ..... |
| Diff..... | ..... | ..... | ..... | 22.3046 | 4.4346 | ..... | 23.2773 | 3.6703 | ..... | 22.1136 | 3.3336 | ..... |
| Air..... | ..... | ..... | 17.8467 | ..... | ..... | 17.0589 | ..... | ..... | 16.5438 | ..... | ..... | 16.362 |
| Diff..... | ..... | ..... | 2.5452 | ..... | ..... | 1.6483 | ..... | ..... | 1.6484 | ..... | ..... | 1.7332 |

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TABLE 91.—Continued.

| 1912. | January 5. | | | January 6. | | | January 7. | | | January 8. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| 0..... | 14.0834 | 14.0834 | 14.0834 | 13.332 | 13.332 | 13.332 | 12.6048 | 12.6048 | 12.6048 | 11.8594 | 11.8594 | 11.8594 |
| Diff..... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 14.3925 | 14.7258 | 14.2046 | 13.744 | 14.0743 | 13.4226 | 12.8169 | 13.0744 | 12.7381 | 12.0775 | 12.4351 | 11.926 |
| Diff..... | 0.3091 | 0.6424 | 0.1212 | 0.412 | 0.7423 | 0.0906 | 0.2121 | 0.4696 | 0.1333 | 0.2181 | 0.5757 | 0.0665 |
| 10..... | 14.5985 | 14.7561 | 14.3500 | 13.9016 | 14.1167 | 13.7632 | 12.9926 | 13.2138 | 12.8714 | 12.2109 | 12.4684 | 12.0351 |
| Diff..... | 0.5151 | 0.6727 | 0.2666 | 0.5696 | 0.7647 | 0.4312 | 0.3878 | 0.6090 | 0.2666 | 0.3514 | 0.609 | 0.1756 |
| 20..... | 14.8954 | 14.9318 | 14.5561 | 14.3117 | 14.2228 | 13.938 | 13.2714 | 13.3623 | 13.0714 | 12.5139 | 12.529 | 12.223 |
| Diff..... | 0.812 | 0.8484 | 0.4727 | 0.9797 | 0.8908 | 0.606 | 0.6686 | 0.7575 | 0.4666 | 0.6544 | 0.6606 | 0.3635 |
| 30..... | 15.2863 | 15.0742 | 14.8773 | 14.5682 | 14.3319 | 14.1925 | 13.6471 | 13.5077 | 13.3441 | 12.829 | 12.7411 | 12.5442 |
| Diff..... | 1.2029 | 0.9908 | 0.7939 | 1.2362 | 0.9999 | 0.8605 | 1.6423 | 0.9029 | 0.7393 | 0.9696 | 0.8817 | 0.6847 |
| 40..... | 15.8014 | 15.1803 | 15.3000 | 15.0166 | 14.5106 | 14.4228 | 14.0289 | 13.6047 | 13.5441 | 13.1077 | 12.8775 | 12.7684 |
| Diff..... | 1.718 | 1.0969 | 1.2196 | 1.6846 | 1.1786 | 1.0908 | 1.4241 | 0.9999 | 0.9383 | 1.2483 | 1.018 | 0.909 |
| 100%... | 26.75 | 17.638 | ..... | 23.65 | 18.083 | ..... | 21.00 | 16.22 | ..... | 19.50 | 15.38 | ..... |
| Diff..... | 12.6666 | 3.5546 | ..... | 10.316 | 4.751 | ..... | 8.3952 | 3.0152 | ..... | 7.6406 | 3.5295 | ..... |
| Air..... | ..... | ..... | 15.6045 | ..... | ..... | 15.0591 | ..... | ..... | 13.8471 | ..... | ..... | 13.2841 |
| Diff..... | ..... | ..... | 1.5211 | ..... | ..... | 1.7271 | ..... | ..... | 1.2423 | ..... | ..... | 1.9818 |

TABLE 91.—Continued.

| 1912. | January 9. | | | January 10. | | | January 11. | | | January 12. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| 0..... | 11.3019 | 11.3019 | 11.3019 | 11.2716 | 11.2716 | 11.2716 | 11.5624 | 11.5624 | 11.5624 | 11.5867 | 11.5867 | 11.5867 |
| Diff..... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 11.5564 | 11.9321 | 11.4231 | 11.4473 | 11.8018 | 11.314 | 11.6836 | 11.923 | 11.4231 | 12.0472 | 12.0897 | 11.6473 |
| Diff..... | 0.2545 | 0.6302 | 0.1312 | 0.1757 | 0.5302 | 0.0424 | 0.1212 | 0.3605 | -0.1393 | 0.4605 | 0.5029 | 0.0605 |
| 10..... | 11.7806 | 11.9836 | 11.5261 | 11.6533 | 11.7776 | 11.4352 | 11.8412 | 11.9533 | 11.514 | 11.926 | 12.1503 | 11.7382 |
| Diff..... | 0.4787 | 0.6817 | 0.2242 | 0.3817 | 0.5060 | 0.1636 | 0.2787 | 0.3908 | -0.0484 | 0.3393 | 0.5635 | 0.1514 |
| 20..... | 12.0472 | 12.1351 | 11.7079 | 11.8776 | 11.9836 | 11.6473 | 12.1200 | 12.0897 | 11.7261 | 12.1200 | 12.2442 | 11.9503 |
| Diff..... | 0.7453 | 0.8332 | 0.406 | 0.606 | 0.712 | 0.3757 | 0.5575 | 0.5272 | 0.1636 | 0.5332 | 0.6575 | 0.3635 |
| 30..... | 12.3563 | 12.2805 | 12.023 | 12.1806 | 12.1654 | 11.920 | 12.3502 | 12.2351 | 11.9503 | 12.4169 | 12.4078 | 12.1321 |
| Diff..... | 1.0544 | 0.9786 | 0.7211 | 0.909 | 0.8938 | 0.6484 | 0.7878 | 0.6726 | 0.3878 | 0.8302 | 0.8211 | 0.5453 |
| 40..... | 12.6108 | 12.3624 | 12.223 | 12.4593 | 12.2533 | 12.1442 | 12.5684 | 12.3624 | 12.1684 | 12.6714 | 12.5229 | 12.3927 |
| Diff..... | 1.3089 | 1.0605 | 0.9211 | 1.1677 | 0.9617 | 0.8726 | 1.0059 | 0.7999 | 0.609 | 1.0647 | 0.9362 | 0.806 |
| 100%... | 17.8 | 15.0 | ..... | 17.5 | 14.83 | ..... | 17.5 | 14.83 | ..... | 17.0 | 14.444 | ..... |
| Diff..... | 6.4981 | 3.6981 | ..... | 6.2284 | 3.5584 | ..... | 5.9375 | 3.2675 | ..... | 5.4132 | 2.8572 | ..... |
| Air..... | ..... | ..... | 12.8472 | ..... | ..... | 12.9987 | ..... | ..... | 13.3623 | ..... | ..... | 13.2411 |
| Diff..... | ..... | ..... | 1.5453 | ..... | ..... | 1.7271 | ..... | ..... | 1.7909 | ..... | ..... | 1.6544 |

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TABLE 91.—Continued.

| 1912, | January 13, | | | January 14, | | | January 15, | | | January 16, | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| 0..... | 11.1019 | 11.1019 | 11.1019 | 10.9383 | 10.9383 | 10.9383 | 11.0352 | 11.0352 | 11.0352 | 11.1504 | 11.1504 | 11.1504 |
| Diff.... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 11.32 | 11.6867 | 11.7564 | 11.1625 | 11.3594 | 10.908 | 11.2655 | 11.6442 | 11.1504 | 11.2655 | 11.6139 | 11.6352 |
| Diff..... | 0.2181 | 0.5847 | 0.6544 | 0.2242 | 0.4211 | −0.0303 | 0.2302 | 0.606 | 0.1151 | 0.1151 | 0.4635 | 0.5848 |
| 10..... | 11.4837 | 11.7412 | 11.3291 | 11.211 | 11.4231 | 11.014 | 11.514 | 11.7109 | 11.6352 | 11.4776 | 11.6745 | 11.2716 |
| Diff..... | 0.3817 | 0.6383 | 0.2271 | 0.2727 | 0.4848 | 0.0757 | 0.4787 | 0.6756 | 0.5999 | 0.3272 | 0.5241 | 0.1212 |
| 20..... | 11.7564 | 11.8473 | 11.5382 | 11.4231 | 11.5291 | 10.2413 | 11.6655 | 11.7867 | 11.4685 | 11.6836 | 11.8139 | 11.5291 |
| Diff..... | 0.6544 | 0.7453 | 0.4362 | 0.4848 | 0.5908 | −0.697 | 0.6302 | 0.7514 | 0.4332 | 0.5332 | 0.6635 | 0.3767 |
| 30..... | 12.0048 | 12.0048 | 11.7715 | 11.6533 | 11.6958 | 11.417 | 11.9321 | 11.923 | 11.6291 | 11.920 | 11.9988 | 11.6897 |
| Diff..... | 0.9029 | 0.9029 | 0.6695 | 0.715 | 0.7575 | 0.4787 | 0.8968 | 0.8877 | 0.5938 | 0.7696 | 0.8484 | 0.5393 |
| 40..... | 12.223 | 12.120 | 11.9533 | 11.9079 | 11.8018 | 11.6503 | 12.1503 | 12.026 | 11.7867 | 12.1321 | 12.1109 | 11.9351 |
| Diff..... | 1.1211 | 1.018 | 0.8514 | 0.9696 | 0.8635 | 0.712 | 1.115 | 0.8908 | 0.7515 | 0.9817 | 0.9605 | 0.7847 |
| 100%... | 17.0 | 14.72 | ..... | 16.8 | 14.72 | ..... | 17.00 | 14.777 | ..... | 17.00 | 14.888 | ..... |
| Diff..... | 5.898 | 3.618 | ..... | 5.8617 | 3.7817 | ..... | 5.9647 | 3.7417 | ..... | 5.8496 | 3.7376 | ..... |
| Air..... | ..... | ..... | 12.5745 | ..... | ..... | 12.6957 | ..... | ..... | 12.5139 | ..... | ..... | 12.9987 |
| Diff..... | ..... | ..... | 1.4726 | ..... | ..... | 1.7574 | ..... | ..... | 1.4787 | ..... | ..... | 1.8483 |

TABLE 91.—Continued.

| 1912. | January 17. | | | January 19. | | | January 22. | | | January 24. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| 0..... | 11.5443 | 11.5443 | 11.5443 | 13.5138 | 13.5138 | 13.5138 | 13.8713 | 13.8713 | 13.8713 | 14.544 | 14.544 | 14.544 |
| Diff..... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 11.6958 | 12.1806 | 11.6442 | 13.6471 | 14.044 | 13.6168 | 14.041 | 14.3076 | 13.9258 | 14.7076 | 14.9227 | 14.547 |
| Diff..... | 0.1515 | 0.6363 | 0.0999 | 0.1333 | 0.5302 | 0.103 | 0.1696 | 0.4363 | 0.0545 | 0.1636 | 0.3787 | 0.003 |
| 10..... | 11.9018 | 12.2078 | 11.7109 | 13.8471 | 14.044 | 13.6653 | 14.1622 | 14.3016 | 13.9804 | 14.8591 | 15.0288 | 14.6167 |
| Diff..... | 0.3575 | 0.6635 | 0.1666 | 0.3333 | 0.5302 | 0.1515 | 0.2908 | 0.4302 | 0.109 | 0.3151 | 0.4848 | 0.0727 |
| 20..... | 12.0594 | 12.2805 | 11.8624 | 14.047 | 14.1349 | 13.8117 | 14.3622 | 14.4015 | 14.0592 | 15.0894 | 15.1197 | 14.8864 |
| Diff..... | 0.5151 | 0.7362 | 0.3181 | 0.5332 | 0.6211 | 0.2979 | 0.4908 | 0.5302 | 0.1878 | 0.5454 | 0.5757 | 0.3424 |
| 30..... | 12.3563 | 12.4745 | 12.1866 | 14.2713 | 14.2955 | 14.0743 | 14.5864 | 14.5864 | 14.3682 | 15.3318 | 15.259 | 15.0288 |
| Diff..... | 0.812 | 0.9302 | 0.6423 | 0.7575 | 0.7817 | 0.5605 | 0.715 | 0.715 | 0.4969 | 0.7878 | 0.715 | 0.4848 |
| 40..... | 12.6048 | 12.6138 | 12.3927 | 14.5561 | 14.4803 | 14.2713 | 14.7682 | 14.7561 | 14.65 | 15.5257 | 15.4378 | 15.3166 |
| Diff..... | 1.0695 | 1.0695 | 0.8484 | 1.0423 | 0.9695 | 0.7575 | 0.8908 | 0.6847 | 0.7787 | 0.9817 | 0.8938 | 0.7726 |
| 100%... | 17.00 | 15.222 | ..... | 18.90 | 16.388 | ..... | 19.00 | 17.00 | ..... | 19.50 | 17.777 | ..... |
| Diff..... | 5.4557 | 3.6777 | ..... | 5.3882 | 2.8742 | ..... | 5.1286 | 3.1286 | ..... | 4.956 | 3.233 | ..... |
| Air..... | ..... | ..... | 13.9077 | ..... | ..... | 15.8469 | ..... | ..... | 15.7863 | ..... | ..... | 16.1499 |
| Diff..... | ..... | ..... | 2.3634 | ..... | ..... | 2.3331 | ..... | ..... | 1.0150 | ..... | ..... | 1.0059 |

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TABLE 91.—Continued.

| 1912. | January 30. | | | February 6. | | | February 14. | | | February 28. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse. | Cow. | Sheep. | Horse | Cow. | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| 0..... | 13.8652 | 13.8652 | 13.8652 | 13.3804 | 13.3804 | 13.3804 | 13.1986 | 13.1986 | 13.1986 | 17.5012 | 17.5012 | 17.5012 |
| Diff..... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 13.9683 | 14.3803 | 14.0592 | 13.541 | 13.8349 | 13.3471 | 13.1986 | 13.1805 | 12.5654 | 17.6649 | 17.6649 | 17.271 |
| Diff..... | 0.103 | 0.5151 | 0.1939 | 0.1606 | 0.4545 | -0.0333 | 0.0 | -0.0181 | -0.6332 | 0.1637 | 0.1637 | -0.2362 |
| 10..... | 14.1076 | 14.4046 | 15.8317 | 13.7531 | 13.8986 | 13.3926 | 13.4229 | 13.2259 | 12.6199 | 17.7861 | 17.6649 | 17.271 |
| Diff..... | 0.2424 | 0.5393 | 1.9664 | 0.3727 | 0.5181 | 0.0121 | 0.2243 | 0.0272 | -0.5787 | 0.2849 | 0.1637 | -0.2362 |
| 20..... | 14.2773 | 14.3985 | 14.1804 | 14.0289 | 13.938 | 13.5834 | 13.6895 | 13.2411 | 12.7714 | 17.9679 | 17.6649 | 17.3017 |
| Diff..... | 0.412 | 0.5332 | 0.3151 | 0.6485 | 0.5575 | 0.203 | 0.4909 | 0.0424 | -0.4272 | 0.4667 | 0.1637 | -0.1995 |
| 30..... | 14.544 | 14.6046 | 14.3319 | 14.1501 | 14.1228 | 13.8107 | 13.7501 | 13.3623 | 13.1956 | 18.180 | 17.7558 | 17.6043 |
| Diff..... | 0.6788 | 0.7393 | 0.4666 | 0.7697 | 0.7423 | 0.4362 | 0.5515 | 0.1636 | -0.003 | 0.6788 | 0.2546 | 0.1631 |
| 40..... | 14.7742 | 14.8167 | 14.6046 | 14.2561 | 14.3167 | 14.0634 | 13.8622 | 13.6895 | 13.332 | 18.283 | 18.0103 | 17.9073 |
| Diff..... | 0.909 | 0.9514 | 0.7394 | 0.8757 | 0.9362 | 0.7029 | 0.6636 | 0.4909 | 0.1333 | 0.782 | 0.5091 | 0.4061 |
| 100%... | 18.50 | 17.22 | ..... | 18.00 | 17.22 | ..... | 17.00 | 17.00 | ..... | 22.00 | 20.5555 | ..... |
| Diff..... | 4.6347 | 3.3547 | ..... | 4.6196 | 3.8395 | ..... | 3.8014 | 3.8014 | ..... | 4.4988 | 3.0543 | ..... |
| Air..... | ..... | ..... | 15.4833 | ..... | ..... | 15.3015 | ..... | ..... | 17.8467 | ..... | ..... | ..... |
| Diff..... | ..... | ..... | 1.6181 | ..... | ..... | 1.9211 | ..... | ..... | 4.6481 | ..... | ..... | ..... |

TABLE 91.—Concluded.

| 1912. | March 15. | | | March 27. | | | April 10. | | |
|---|---|---|---|---|---|---|---|---|---|
| Amount in tons. | Horse | Cow | Sheep. | Horse. | Cow. | Sheep. | Horse. | Cow. | Sheep. |
| 0..... | 19.93 | 19.93 | 19.93 | 18.19 | 18.19 | 18.19 | 19.00 | 19.00 | 19.00 |
| Diff..... | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5..... | 20.11 | 20.00 | 19.77 | 18.222 | 18.19 | 17.915 | 19.055 | 18.885 | 18.75 |
| Diff..... | 0.18 | 0.07 | -0.16 | 0.032 | 0.0 | -0.275 | 0.055 | -0.115 | -0.25 |
| 10..... | 20.22 | 20.00 | 19.77 | 18.25 | 18.205 | 17.94 | 19.055 | 18.885 | 18.75 |
| Diff..... | 0.29 | 0.07 | -0.16 | 0.06 | 0.015 | -0.25 | 0.055 | -0.115 | -0.25 |
| 20..... | 20.25 | 20.00 | 19.77 | 18.38 | 18.205 | 17.985 | 19.055 | 18.885 | 18.75 |
| Diff..... | 0.32 | 0.07 | -0.18 | 0.19 | 0.015 | -0.205 | 0.055 | -0.115 | -0.25 |
| 30..... | 20.27 | 20.16 | 20.05 | 18.555 | 18.320 | 18.205 | 19.333 | 19.110 | 19.00 |
| Diff..... | 0.34 | 0.23 | 0.12 | 0.365 | 0.13 | 0.015 | 0.333 | 0.110 | 0.0 |
| 40..... | 20.50 | 20.27 | 20.16 | 18.665 | 18.470 | 18.320 | 19.525 | 19.250 | 19.165 |
| Diff..... | 0.57 | 0.34 | 0.23 | 0.475 | 0.280 | 0.130 | 0.525 | 0.250 | 0.165 |
| 100%..... | 21.50 | 20.83 | ..... | 19.333 | 19.275 | ..... | 20.111 | 20.111 | ..... |
| Diff..... | 1.570 | 0.909 | ..... | 1.143 | 1.085 | ..... | 1.111 | 1.111 | ..... |
| Air..... | ..... | ..... | 18.7557 | ..... | ..... | ..... | ..... | ..... | ..... |
| Diff..... | ..... | ..... | 1.2545 | ..... | ..... | ..... | ..... | ..... | ..... |

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TABLE 92.—EFFECT OF DECOMPOSITION OF MANURE ON TEMPERATURE OF SOIL. AVERAGES FOR THE WHOLE PERIOD.

| Amount of manure. | Horse. | Cow. | Sheep. |
|---|---|---|---|
| | C° | C° | C° |
| 0 tons | 13.90 | 13.90 | 13.90 |
| 5 tons | 14.10 | 14.35 | 13.98 |
| 10 tons | 14.26 | 14.39 | 14.10 |
| 20 tons | 14.50 | 14.48 | 14.13 |
| 30 tons | 14.79 | 14.65 | 14.45 |
| 40 tons | 15.13 | 14.81 | 14.70 |
| 100% | 23.33 | 17.16 | ..... |
| Air | ..... | ..... | 15.13 |

The above tables contain the temperature in F. degrees for the days the records were made, the difference for the corresponding days between the 0.0 manure with any of the other amounts of manure, and the average temperature for the whole period or at the expiration of the experiment, for all the various amounts and different kinds of manure. The data show that in the first day of the experiment the temperature of the soil with the 5, 10, and 20 tons of manure of all three kinds, was lower than that of the soil with 40 tons and 100% of manure. At the end of the first day, or at the beginning of the second day, the temperature of all the soils containing the different manures in the various quantities was appreciably higher than that of the check and increased regularly and gradually with the increase in the amount of manure. The rise in all cases tended to increase till the maximum was reached and then showed a tendency to decrease but remained quite constant for a long period and varied with the air temperature. On account of the variation in air temperature it is somewhat difficult to state definitely when the maximum temperature was attained by all the different manures. The results seem to show, however, that this was attained at different days by the different kinds as well as by the different amounts of manure but practically on the third, fourth and fifth day. The larger quantities of every kind of manure attained the maximum temperature earlier than the smaller quantities. The horse manure attained the highest temperature first, followed by cow and sheep one day later. The magnitude of rise of temperature was also in the same order. The maximum temperature given by the 40 tons of the horse manure was 2.18° C., of the cow 1.27°, and of the sheep 1.28° and by the 10 tons of the horse manure .5696°, cow .7847°, and sheep .4312°. While the highest temperature reached by 100% horse manure was 23.27° C. and by the same percent of cow manure 3.67° C. The check or the unmanured soil was taken as a unit in every case.

After the highest point was reached the temperature began to decrease slowly but on the whole it remained quite constant almost to the end of January. During this time it varied from day to day with the air temperature. By the middle of February it began to become somewhat imperceptible among the different kinds of manure as well as among the different amounts within the same kind of manure. In fact

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the temperature of the sheep manure began to become less than that of the check.

When the daily records, or for those days that the records were taken, are arranged in averages for the whole period, namely, from December 28th to April 10th, it is found that in every case the rise of temperature increased very regularly and gradually with the increase in the amount of manure so that the difference between the soil with no manure and that containing 40 tons of manure was for horse manure 1.23°, for cow manure .91°, and for the sheep manure, .80° C.; while the difference between no manure and 10 tons of manure was for the horse manure .30°, for cow .49°, and for sheep .20° C.

From these results it would seem that the application of 40 tons of manure and especially of horse manure, would raise the soil temperature quite appreciably above that of the unmanured soil and keep it warmer for a long period, but such heavy applications or dressings are very seldom applied. The most common and practical dressing is about 10 tons to the acre. This amount raised the temperature of the soil about half a degree and at the end of the whole period this soil was only about a quarter of a degree warmer than the wholly unmanured soil. This warmth or rise is unimportant for practical conditions; it is too small to have any important influence. Furthermore, when it is considered that the decomposition processes require a high temperature for their maximum activity, then manure, even in fairly large amounts, can add no or very little heat to the soil at the time when the latter needs it the most.

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## SUMMARY.

In this bulletin there is presented the results of an investigation upon the general subject of soil temperature. It was shown at the outset that the problem is very complex—it involves a variety of factors—and in order to arrive at proper and definite conclusions it must be studied from as broad a standpoint as possible. The attempt was made and the results obtained may be summarized as follows:

The specific heat of different types of soil, gravel, sand, loam, clay and peat, in dry condition did not differ very materially; this was true both by equal weights as well as by equal volumes. The specific heat of peat was about half as great as that given to it by other investigators. The moisture content of these different soils in their natural condition varied very greatly and since water has such high specific heat, it made a tremendous difference in their final specific heat.

The heat transference in these different soils was measured (1) in their dry condition; (2) in their natural state under laboratory conditions; and (3) under field conditions. It was found in all these three states that the order of heat conductivity was the same: gravel possessed the highest heat transmitting power, followed in order by sand, clay, loam and peat, respectively. Convectional currents, molecular diffusion and distillation influenced very greatly the rate of flow of heat, and consequently the values obtained do not represent the true heat conducting power of these different types of soil.

In field conditions, the solar radiation tended to travel with greater rapidity and facility vertically than horizontally.

The study on radiation showed that color had no effect upon radiation, which is contrary to the common belief, but it had upon absorption; that the different types of soil tended to radiate differently when dry, about the same and more when well moistened and in their natural condition, and that a dry surface or mulch reduced the radiation. In the dry state, sand exhibited the highest radiating power followed by gravel, clay, loam, and peat respectively. The water, however, had by far the highest radiation capacity of any soil either in the dry or moist state.

When the temperature of these different types of soil (all covered with a thin layer of the same kind of soil in order to eliminate the factor of color, and other factors) was studied under field conditions, it was found that they all cooled and froze about the same time in the upper 6 inches, but in the spring they thawed and warmed up at different rates. This was attributed to their different specific heats and to the downward and upward trend of air temperature in the fall and spring respectively. The gravel and sand thawed first, followed by clay 1 day later, loam 2 days later, and peat 10 days later. The temperature of the first two soils rose very rapidly after thawing, while that of the others rose very slowly. When the lower depths of the latter soils had thawed, however, their temperature rose also quite rapidly and finally reached the same degree of magnitude as in the former or lighter soils,

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and all continued to have almost the same temperature from then on throughout the summer, autumn and winter.

This equal degree of warmth of all these different types of soil during the warm part of the year and especially during the summer season, was believed to be due largely to the thin layer of the same kind of soil with which they were all covered. This thin layer of soil tended to equalize the amount of heat that penetrated into these different kinds of soils by eliminating the differences of their color and by equalizing, to a large extent, the amount and rate of evaporation of their moisture. If it had not been for this external layer of soil these different soil types would have taken in unequal amounts of heat and consequently their temperature would have been different. This point, however, is now under investigation.

Of all these different types of soil, sand showed the greatest amplitude and was followed by gravel, clay, loam, and peat, respectively. The greatest monthly fluctuation for all soils occurred in June and the least in February.

The different meteorological elements played a great part in the temperature of these soils, but on account of the complexity of their behavior it was difficult to trace the direct influence of all of them. The influence of the most important ones was discussed in detail.

The results from the investigation on the effect of organic matter on soils temperature showed that the rate of thawing was about proportional to the amount of organic matter present, but that after thawing the temperature of the soils containing 2.01, 3.32, 5.47 and 6.95% organic matter was higher throughout the summer than the temperature of the white sand and of the peat. The temperature of these last two soils was about the same during the warmer part of the year, but during the cold seasons the peat had a higher temperature. The magnitude of the amplitude of all these soils behaved in the same order as the average temperature.

The conditions of cultivation, noncultivation and sod had a very distinct effect upon the soil temperature. During the winter all three plots had about the same temperature with a small difference in favor of the sod. In the spring the sod and uncultivated plots thawed first and the cultivated plot about one day later, at the 7 inches depth. The temperature of the sod plot rose several degrees above that of the other two plots and continued to be in excess until the plants had made a considerable growth, and then it dropped below that of the two bare plots, and remained so throughout the summer months, but when the cold period came the order was reversed,—the temperature of the bare plots fell below that of the sod plot and continued to be lower throughout the second winter. The temperature of the cultivated plot rose slightly higher than that of the uncultivated, after thawing, and continued to be slightly higher during the early part of the spring season or up to about the middle of May, and then the uncultivated plot became the warmer and remained so throughout the whole summer. During the fall both plots had about the same temperature with a slight difference in favor of the uncultivated plot. The difference in temperature between these two plots was explained upon the following general facts: (1) Different rate of evaporation; (2) different rate of heat conductivity; (3) differ-

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ence in temperature at the lower depths, and (4) the effect of the dry mulch of the cultivated soil.

Salt solutions had a very marked influence on the rising and lowering of soil temperature. Different salt solutions of the same density or the same solution of different densities raised the soil temperature considerably. Their influence was also very pronounced on the rate and degree of lowering of temperature, as well as on the rate of thawing.

The different kinds of manure raised the soil temperature differently,—horse manure the most, sheep manure the least, and the cow manure intermediate. In every case the greatest rise took place in the first three or four days. The rise increased with the increase in quantity. The degree of rise is probably insignificant for practical conditions.

It is thus seen that the general subject of soil temperature is very complex, that the number of factors influencing it is very large, that the effect of these different factors may be direct or indirect, dependent or independent, large or small, and that some of these factors can be controlled and others cannot, for the final modification of soil temperature.

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DIVISION OF BACTERIOLOGY.

# A BACTERIAL DISEASE OF JUNE BEETLE LARVÆ, *LACHNOSTERNA* SPP.

BY

ZAE NORTHRUP

EAST LANSING, MICHIGAN.
1914

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## FOREWORD.

The present bulletin appeals to the entomological worker because it helps to explain the excessive mortality that sometimes occurs when white grubs become exceptionally plentiful.

It is to be hoped that opportunity for further experiments may be forthcoming in order that confirmatory evidence may be obtained together with more detail regarding conditions favorable to the propagation and spread of the disease.

R. H. PETTIT,
Entomologist Exp. Station.

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# A BACTERIAL DISEASE OF THE LARVÆ OF THE JUNE BEETLE, *LACHNOSTERNA* SPP.

BY ZAE NORTHRUP.

WITH TWENTY-TWO ILLUSTRATIONS.

The "white grub" or larva of the May or June beetle, *Lachnosterna* spp. was brought forcibly to the notice of the farmers during the summer of 1912 on account of the serious depredations to various crops. This is by no means the first year that the ravages of these insect larvæ have been recorded. Their activities were known as early as the middle of the seventeenth century (1) and have continued to be remarked with more or less regularity every few years up to the present time (2-12 inclusive).

These insect larvæ known locally as "caculo" or "gusano blanco" are also a serious pest to the sugar cane in Porto Rico (13).

These larvæ have a life cycle of at least three years, but rarely do noticeable damage during the first year of their existence because of their relatively small size; the second and third years however, are often marked by serious ravages to crops and to grass land.

Up to the present time, in the United States no artificial remedies have been in any way successful in controlling the numbers and proportionate depredations of these grubs, nor have the natural means of suppression been sufficiently potent. Hogs and fowls allowed to run on newly plowed land eat the grubs, but this or similar remedial measures can be used evidently only under restricted conditions. Two species of blackbird in Porto Rico are very active in following the plow, searching for and eating the white grubs (13).

A remedy which would fill the real need is one which would act *in situ*. Such provision for holding the white grub in check is found in the insect parasites and parasitic fungi. Up to the present time at least nine other insects, three species of fungi and two species of bacteria (14) are known to attack the larvæ of *Lachnosterna* spp. and related genera. This article describes a third bacterial infection due to a micrococcus, the characteristic lesions of which were apparently described by Krassilstschik but were attributed to a "decomposition of the epidermis provoked by a rupture of the cuticle whose elasticity is somewhat limited" (translation).

Mr. Xavier Raspail in his article in the "Mémoires de la Sociétié Zoologique de France" says 'efficacious animal parasites of this insect are unknown' (13).

Some twelve years ago, cultures of a parasitic fungus, *Isaria densa* (*Botrytis tenella*) were for sale in France as a remedial measure against the larvæ of the European May beetle, *Melolontha vulgaris*. The results obtained were very variable.

Mr. le Moult stated however that the results of inoculation of the soils of the Canton of Gorrow in 1891 and 1892 exceeded all hopes; the ruin caused by the white grubs was followed by affluence and the parasites used



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in the soil still continued their destructive action on the grubs produced by beetles from neighboring cantons (13).

Pettit (15) in his bulletin on "Insects of the Garden" is among the few to mention the fact that these larvæ are subject to diseases; to quote: "these larvæ are especially apt to be killed off by diseases and natural enemies so that they come and go with no apparent reason for so doing. They seldom remain very numerous in one field for more than one or two years, because of these enemies and diseases."*

During the summer of 1912, many complaints came to the Entomological Division of this station of the ravages of the white grub and accompanying the letters in many cases were specimens of the pest. Prof. Pettit noted that a large percentage of the specimens was diseased to a greater or lesser extent. From the previous history of similar infections he had remarked that when the larvæ became infected, the course of the disease was so rapid and the consequent destruction of the larvæ so thorough that healthy specimens were difficult to obtain even early in the season and but few would be found for the next few years; with this in mind, the specimens of the grub and addresses of the farmers sending the same were immediately turned over to the Bacteriological Laboratory with the hope that the cause of the disease might be ascertained and if practicable, used as a remedial measure.

*Pettit now (1914) states that the three year cycle may help to explain the appearance and disappearance of these larvæ.

## PART I.

### EXPERIMENTS WITH LARVÆ OF *LACHNOSTERNA* SPP.

The normal larva is described (15) as a grub, white and soft with the exception of the head and six legs, having a row of spiracles (breathing pores) along the sides, a delicate watery creature with awkward gait and feeble powers of locomotion.

The diseased larva differs from the normal larva in that the affected parts are very black and shiny and are sharply circumscribed. The infection occurs mainly along the joints of the legs, spiracles and upon the dorsal or ventral segments of the white soft portion.

Fig. 1.

Normal larva of *Lachnosterna arcuata*, enlarged one-fourth. Fig. 46 (from Chittenden), 1908 Yearbook of the U. S. Dept. of Agriculture (27).

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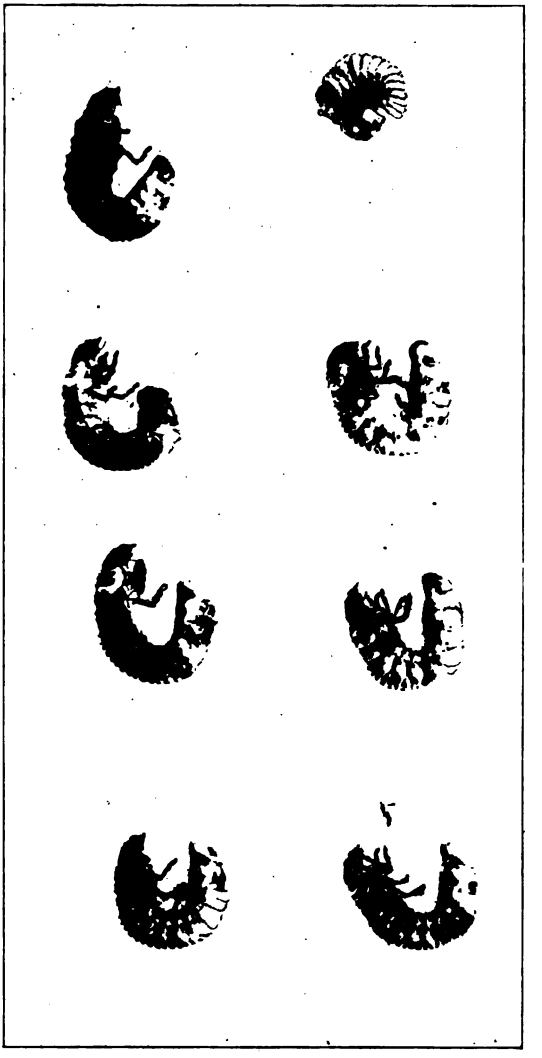

Fig. 2.

June beetle larvæ *Lachnosterna* spp. in successive stages of disease. Natural size.

Badly diseased larvæ are almost entirely black or brownish in color; the whole body often seems to be in a state of advanced putrefaction, yet the larva still shows signs of life.*

It would not be remarkable if the rapid generalization† of this disease occurred after the first infection, because of the nature of the circulatory system, there being no system of closed blood vessels, only a heart and

*It is now thought that this *brown* coloration (*not* the shiny black coloration) of the diseased larvæ is most probably due to the invasion, secondary or primary, of another organism, the gas-bacillus found in the diseased larvæ which appears to be similar to Krasilstschik's bacillus of septicemia, *B. septicus insectorum*. (See p. 17).

†This "generalization" is now thought to be a manifestation of the septicemia-like character of the agent which causes the brown coloration of the larvæ.

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short artery located along the median dorsal line, the blood wandering freely through the body cavity bathing all the tissues (16).

The progressive destructiveness of the disease is most marked in the affections of the legs. In some cases the infection begins at the tip of the leg and as it progresses, the leg, segment by segment, blackens and drops off leaving the stumps shiny, black and sometimes swollen in appearance; in other cases the infection occurs at one of the intermediate joints or at the last joint nearest the body of the grub, the leg in time loosening and breaking off at the point of infection. This phenomenon was apparently noted by Krassilstschik, as follows: "larvæ with one or several, more or less affected legs are found, the parts of which near the body become entirely black." (translation) (see Fig. 2).

Within certain limits neither the size nor the number of infected areas seems to affect the activity of the grub. To quote Krassilstschik again "This (referring to the black spots) does not hinder the larvæ from being in the best state of health, from being transformed into a chrysalid, etc." (translation) Only under certain conditions which will be mentioned later is the activity of the grub lessened, and followed later by death. Most of the grubs examined were very active unless badly infected with the disease.

### ETIOLOGY OF THE DISEASE OF THE JUNE BEETLE LARVÆ.

Smears were made from a dead grub badly infected with the disease, and stained with carbol-fuchsin. Micrococci predominated; there were present also a number of bacteria with rounded ends, in chains.

Smears were also made from the diseased portion of a living grub, an incision being made in the diseased tissues with sterile scissors, the material being obtained with a sterile platinum loop. These preparations were stained with carbol-fuchsin and with Wright's stain and examined with the 1-12 oil immersion lens. Only an occasional preparation contained organisms; these appeared to be micrococci, not perfectly round, occurring as diplococci and tetrads.

Transfers of the infectious material from this incised portion of the larva were made to tubes of sterile broth and slant agar. Plates were made from one of the broth tubes, in ordinary agar.

The twenty-four hour cultures in broth were uniformly cloudy, no ring or pellicle, and a few bubbles of gas were noted; on agar the growth was white, moist, beaded, semi-translucent, not spreading. The plates made from the broth tube inoculated directly from the diseased portion of the living grub gave almost a pure culture of micrococci; this seemed to indicate that this micrococcus was the causal organism. (Pébrine, an infectious disease of silk worms was formerly supposed to be due to a micrococcus, *Micrococcus ovatus*, but is now known to be due to a protozoan (17).

### MORPHOLOGICAL AND CULTURAL CHARACTERISTICS OF THE MICROCOCCUS.

The following observations were made on pure cultures of the micrococcus isolated from the agar plates mentioned above. The cultures were grown at 20°-25°C.

Morphology: Micrococci of varying sizes, 0.9 microns, 1.2 to 1.4 microns diameter with dividing forms; occur singly, in twos (diplococci), threes (triangular), fours (tetrads or diamond-shape), and clumps of more or less regular groupings, the individuals in the groups arranged in a honeycomb-like order (see Figs. 3, 4 and 5); chains of more than three never observed.

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Division in one plane very evident (see Figs. 3 and 4); division in two planes in a single organism was infrequently observed.

Ordinary agar, stroke culture: 7 days, growth abundant, beaded, flat, glistening, slightly contoured, opaque, pale orange-yellow, butyrous consistency, no odor.

Cultures newly isolated are non-pigmented and show very moderate growth; successive subcultures however have a dull yellow-orange color which darkens somewhat with age; the latter show abundant growth.

Dextrose agar stroke culture: 48 hours, growth moderate, limited to line of inoculation, rather membranous; other characters the same as an ordinary agar.

Broth: 48 hours, turbid, no ring or pellicle, no gas.

Larva broth: Same as ordinary broth.

Litmus milk: 7 days, slightly acid, slight reduction, no coagulation, yellowish deposit of bacterial cells at bottom of tube. (Some cultures showed coagulation).

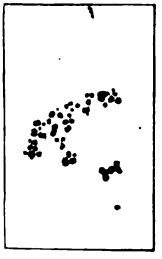

Fig. 3.

*Micrococcus nigrofaciens*, × 1000, from a nine day old dextrose agar culture. Methylen blue. Shows varying sizes and gonococcus-like forms. Zeiss Oc. 8. Leitz Apo. Oil immers. 2 mm. Ap. 1.30.

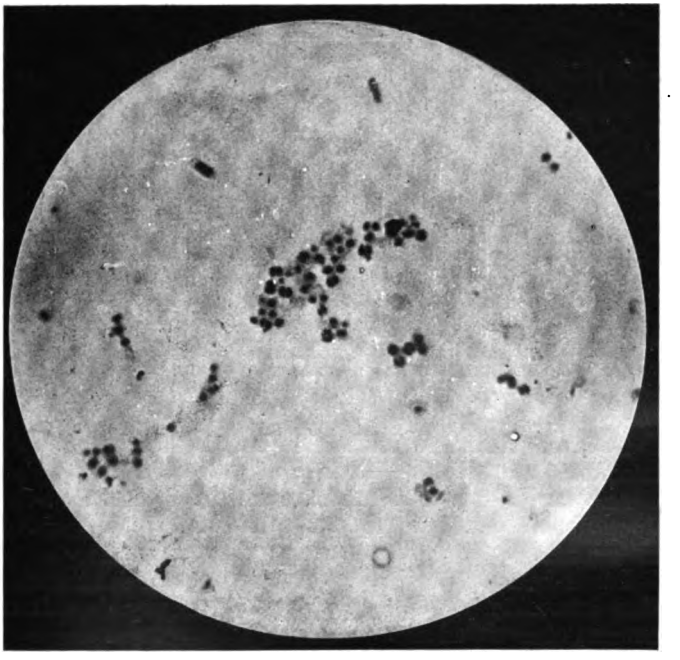

Fig. 4.

*Micrococcus nigrofaciens*, × 1500. Shows varying sizes and gonococcus-like forms. Zeiss Oc. 8. Leitz Apo. Oil immers. 2 mm. Ap. 1.30.

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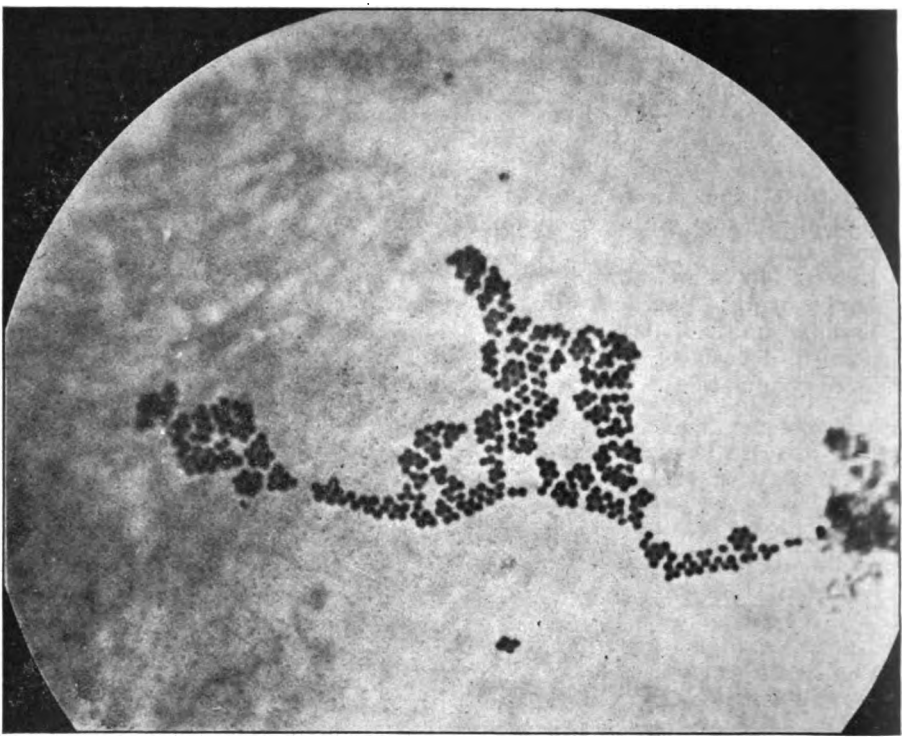

Fig. 5.

*Micrococcus nigrofaciens*, × 2000, six day old larva-medium culture. Gram stain. Zeiss Oc. 8. Leitz Apo. Oil immers. 2 mm. Ap. 1.30. Notice the regular groupings in twos, threes (triangular), tetrads and fours in diamond shape, also in sixes (triangular) and sevens (hexagonal with coccus in center).

Gelatin stab: Within 24 hours, liquefaction crateriform, 2nd day becoming stratiform; liquefaction proceeds but slowly.

Another gelatin stab culture after seven days growth showed only crateriform liquefaction, growth best on surface, line of puncture filiform to beaded at greatest depth. One culture showed viscidity.

Larva-gelatin stab: Best growth at surface at first, crateriform liquefaction becoming napiform to saccate. Heavy deposit of bacterial sediment at base of liquefied sac.

Dextrose, lactose and saccharose fermentation tubes; 48 hours, turbidity in open arm only, no gas.

Maltose peptone solution: 24 hours, very turbid. Older culture shows sediment but no surface growth.

Indol production: Positive but moderate.

For the purpose of checking the above results, this organism was given to one of the students as an "unknown." I am indebted to Mr. C. R. Garlock for the following data concerning the morphological and cultural characteristics of the micrococci predominant in the diseased portions of the white grub.

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Name of microörganism: Unknown, designated as No. 25.
Isolated from: Dextrose agar slant, pure culture.
Occurrence: Not known.
Importance: Not known.
Spore: None observed.
Method of reproduction: Binary fission.
Total organism: Drawings of diplococci and tetrads.
Arrangement: In twos and fours.
Size: 1.2 microns to 1.4 microns in diameter.
Flagella: None.
Involution forms: None.
Capsules or zoöglea: None.
Hanging drop: Drawing shows that the organisms are attracted to the periphery of the drop, demonstrating positive aerotaxis.

Fig. 6.

Agar streak culture three days old, showing separate colonies, natural size.

Fig. 7.

Gelatin stab, larva gelatin culture nine days old. Natural size, showing deposition of granular sediment at bottom of liquefied funnel.

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Nutrient broth: No change the 1st day, turbidity and deposition of sediment takes place gradually until the 5th day, when a decided cloudiness and sediment is evident.

Nutrient gelatin stab: 2nd day, beaded, no liquefaction noted.

Agar streak: 1st day, filiform growth, seems to be made up of small colonies creamy white in color. Colony forms still evident on 2nd day. 4th day, colonies have merged, brownish yellow in color.

Potato culture: 6th day, brownish yellow, restricted growth.

Gelatin plate: 2nd day, colonies 1 mm. to 2.5 mm. in diameter, flat, slightly elevated, smooth edge, interior homogeneously granular.

Agar plate: 11th day, colonies the size of a pin point to 1.5 mm. in diameter, elevation of growth a little more pronounced than on gelatin plate, smooth edge, dense center, rest of colony homogeneously granular.

Color production: As noted under agar and potato cultures.

Production of $NH_3$, $H_2S$ and indol: Gave no reaction with methods employed.

Litmus milk: No change for 10 days, 10th day partial reduction, 11th day acid, curd and more reduction, 14th day complete reduction with some separation of whey.

Reduction of nitrates: Positive reaction.

Fermentation of carbohydrates: No gas production. Peptone water (blank), dextrose, lactose and saccharose give good growth with sedimentation, in open arm only. (Lactose seems the most favorable.) Starch and maltose are much more favorable to luxuriant growth.

These data agree very well with the preceding with the exception of a few particulars as the liquefaction of gelatin, action in litmus milk and indol formation.

Throughout all culture media, almost without exception, this organism shows the tendency to develop in small separate colonies. This is especially marked in whey, larva broth, on the surface of slant agar and in the gelatin cultures.

### STAINING REACTIONS IN CULTURE.

The micrococcus stains best with aqueous-alcoholic dyes; is Gram-positive but negative to the acid-fast stain and to Neisser's stain for metachromatic granules.

An attempt was made in seeking out the nomenclature of this organism but difficulties were met which prevent the fixing of the micrococcus in a definite group. It seems to enter the class with *Micrococcus hemorrhagicus*, with the exception of the size (18). From the characteristic shiny-black lesions produced by this organism it has been named "*Micrococcus nigrofaciens.*"

### PATHOGENICITY OF THE MICROCOCCUS.

Eight larvæ were received from an infected field near Sebewaing, Michigan. One of these was apparently not diseased, three showed infected areas not more than 0.5 mm. in diameter, the remaining four were in an advanced stage of the disease. All but one were very active and this one to all appearances was but slightly affected with the disease.

Soil having no previous history of white grubs was obtained from the garden adjoining the laboratory, placed in large petri dishes and one portion sterilized in the autoclave at 15 lbs. pressure for 3 hours, the other portion baked in the hot air oven at 180°C for 30 minutes.

This latter portion after being sterilized was mixed as aseptically as possible

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with enough sterile water to make the soil of about the same plasticity as when obtained from the garden. A few drops of a broth culture of the micrococcus were then added and mixed thoroughly using aseptic precautions as before. The apparently uninfected larva was washed with a camel's hair brush dipped into a five per cent solution of boric acid, washed off with sterile water and placed in this inoculated soil.

Six days afterward the larva was examined and found to be still apparently perfectly normal. The absence of infection was assumed to be due to the perfect impermeability of the integument. With the possibility in mind that natural infection results from bacterial invasion of accidental abrasions or wounds, or inherent imperfections of the integumental membrane, an incision was made near one of the spiracles, thereby imitating as nearly as possible, supposed actual conditions; the grub was then replaced in the inoculated soil.

Two days later, the larva was again examined and was found to have a characteristic shiny black lesion at the point of incision. The larva was found dead the afternoon of the next day.

It was suggested by Dr. Shafer of the Entomological Department that this supposed lesion which was characteristically black, was perhaps only the blackening of the blood caused by oxidation upon exposure to the air. For determining this point, other larvæ were carefully incised and left exposed to the air for from one to five hours. No blackening of the incised portion occurred in any case. The incision was not evident except as the larva was handled roughly, when the clear colorless blood exuded. (This experiment was made with larvæ of the Southern U. S. June beetle.)

The recovery of the micrococcus from the diseased portion of this larva followed, but whether the organisms were really recovered from the infected part or came from faulty sterilization of the exterior portion of the integument or from those which entered the body by means of the digestive tract could not be determined very well.

In summarizing the above experiment (which was the only one of its kind performed at this time, due to the lack of healthy larvæ) it seems that even this single trial may be taken as at least indicative of several things.

1. That the micrococcus isolated from a diseased larva of the June beetle, *Lachnosterna* spp. is pathogenic to other larvæ of the same species.
2. That this organism must exist in the soil.
3. That infection may occur from without.
4. That if (3) is possible, the diseased larvæ must have become infected through some abrasion of the integument, some imperfection of the joints of the legs or abdomen or through the hair follicles. The following illustrations furnish a defense for this premise. (See Figs. 8, 9, 10.)

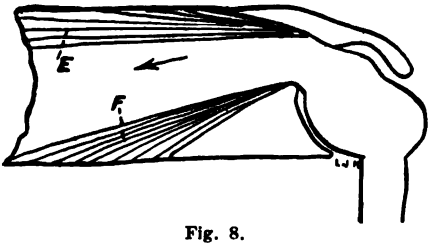


Fig. 8.

Leg joint of an insect. Fig. 22. Packard's Textbook of Entomology. (28) Notice that the muscular structure comes to the surface at the point of articulation. (See Figs. 11 and 12).

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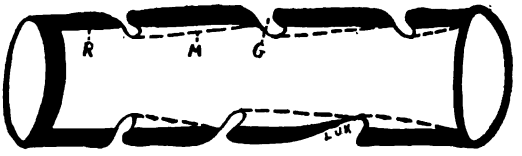


Fig. 9.

Integument, showing chitinous ring of segments with membranous articulation (See Figs. 11 and 12). Fig. 17. Packard's Textbook of Entomology. (28)

At the same time that the healthy grub was placed in artificially infected soil, a second apparently healthy grub was placed in "naturally" infected soil. The latter was soil sent in, containing badly diseased grubs. At the end of five days no infection was apparent so this larva was incised in order to repeat the foregoing experiment. Unfortunately the cut was made so deep as to cause the soft inner body parts to extrude and the larva soon died.

In the effort to repeat the first experiment the incisions all proved fatal. It is very difficult to make an incision in an active grub, even with very sharp pointed scissors on account of the chitinous nature of the integument and unfortunately anesthesia cannot be practiced without fatal results. These several futile attempts resulted in the destruction of the few remaining healthy larvæ and no others could be obtained.

### DEMONSTRATION OF BACTERIA IN DISEASED TISSUES OF LARVÆ OF *LACHNOSTERNA* SPP.

Microtome sections of diseased portions of several larvæ were stained with eosin and methylen blue for the purpose of detecting bacteria in the larval tissues.

Beautiful pictures were thus obtained of the cellular structure of the larvæ. The micrococci were found, unstained, but dark brown in color, in masses in the laminæ of the integument, and in the subnascent cells. The tissues surrounding the microörganisms were also of a dark brown color. (See Fig. 13). Micrococci stained blue were found also, interspersed between the cells of the intestinal wall but were never demonstrated in the body tissues intervening. This seemed to suggest that the black diseased areas were produced by extraneous infection only, although the micrococci found between the cells of the intestinal wall were doubtless the same as those introduced artificially into the soil and those found in the diseased portions of the integument.

The micrococci found in the intestinal tract and walls may exert a similar and perhaps even more powerful influence on the cell activities of the larva than those found in the integument because of the essential difference in the functions of the respective cells and in the nature of their structure.

Irregular shaped masses also staining blue were found interspersed between the cells of the intestinal wall both in the presence and in the absence of micrococci. (See Fig. 17.) The accompanying photomicrographs illustrate the above conditions.

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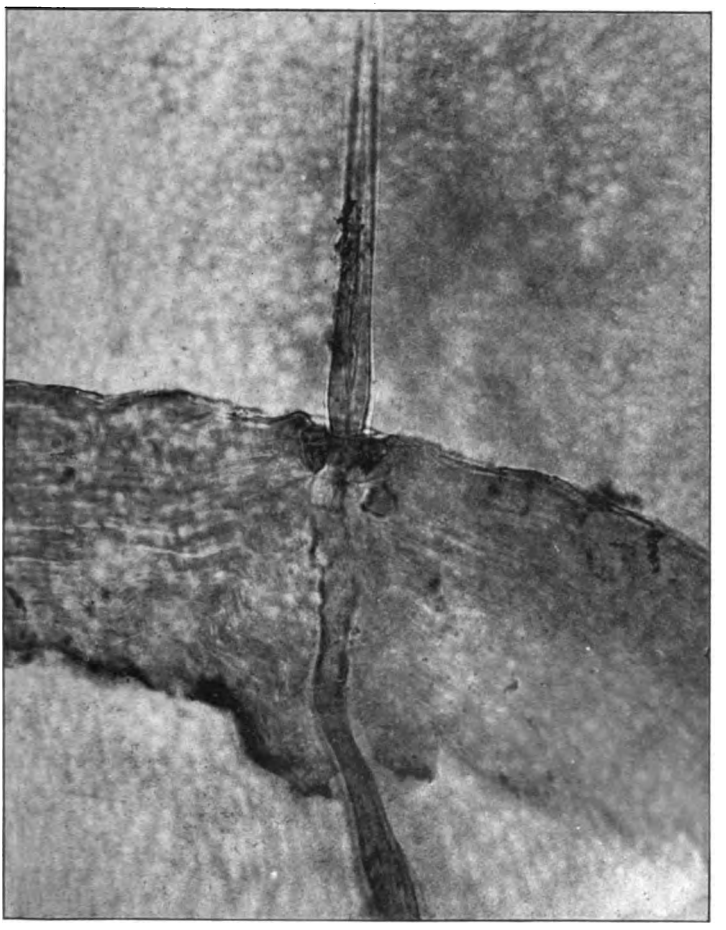

Fig. 10.

Hair, follicle and root (*Lachnosterna* larva), × 600. Zeiss Oc. 2. Leitz Apo. Oil immers. 2 mm. Ap 1.30. Illustrative of how infection may enter from without. See Fig. 20.

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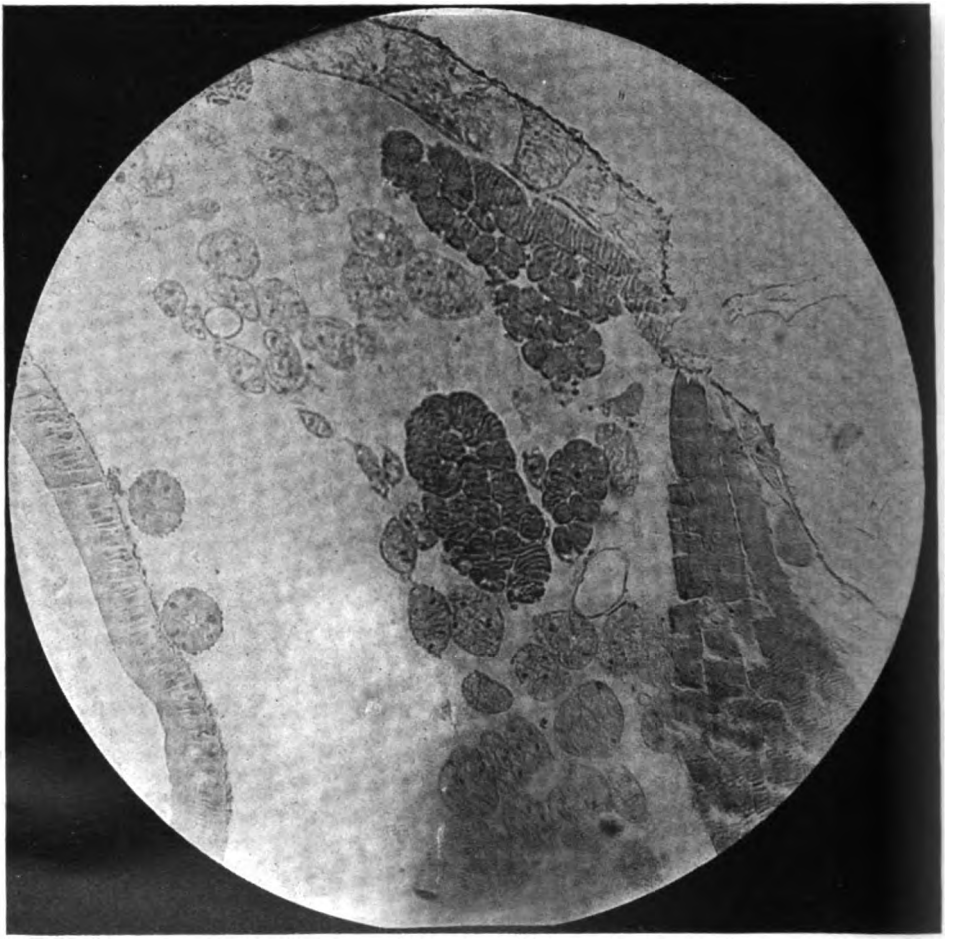

Fig. 11.

Normal tissues, × 100. Zeiss Oc. 2. and Obj. 16. Cross section of larva (*Lachnosterna*) showing character of cells from intestinal wall to the integument. Section stained with eosin and methylen blue. Cells take the eosin only.

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Fig. 12.

Normal and diseased tissues, × 100. Zeiss Oc. 2 and Obj. 16. The diseased tissue is the dark portion of the integument, *not* stained.

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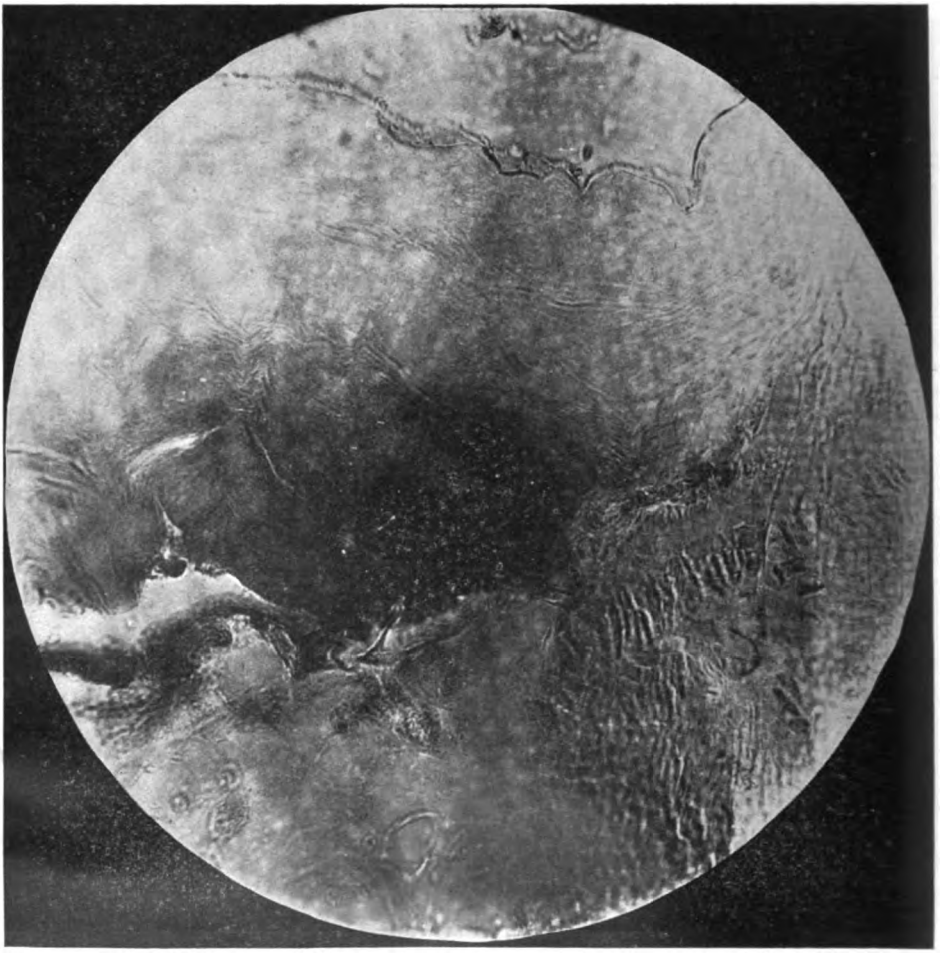

Fig. 13.

Diseased tissue of integument, × 500, section of *Lachnosterna* larva. No cocci evident, showing muscular attachment. Zeiss Oc. 2. Leitz Apo. Oil immers. 2 mm., Ap. 1.30.

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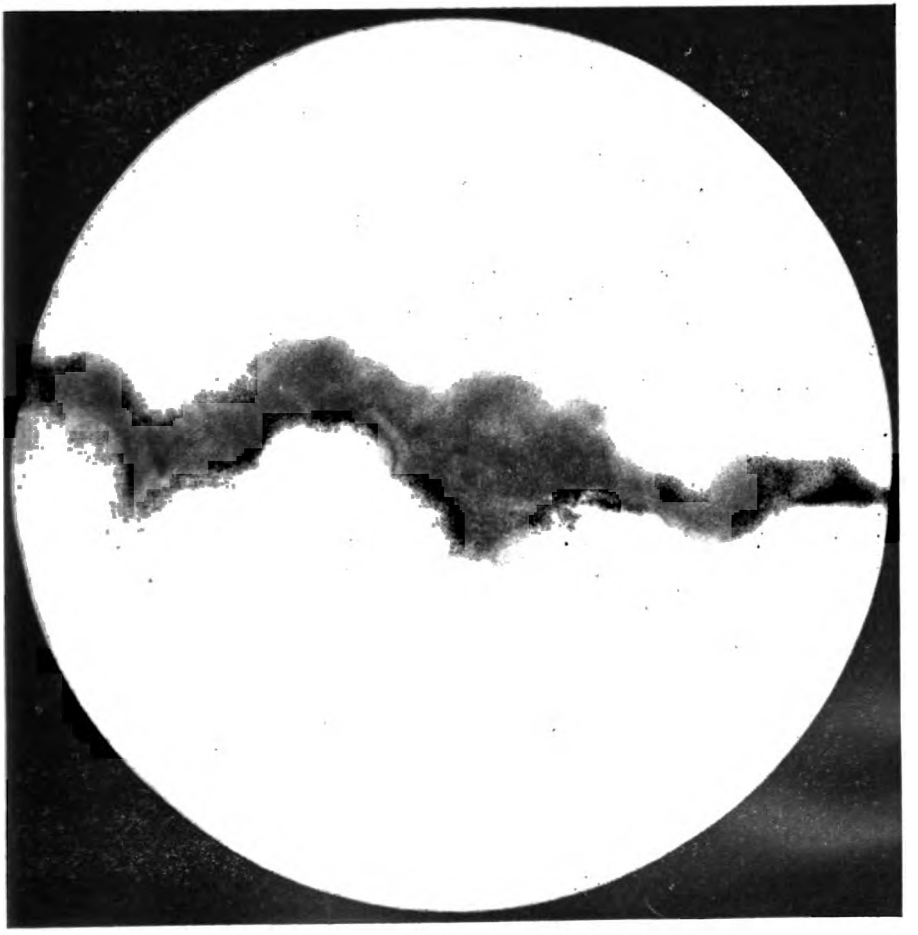

Fig. 14.

*Micrococcus nigrofaciens*, × 1000, entering the integument from without. Section of *Allorhina nitida*. Gram + eosin + KOH. Zeiss Oc. 4. Leitz Apo. Oil immers. 2 mm., Ap. 1.30.

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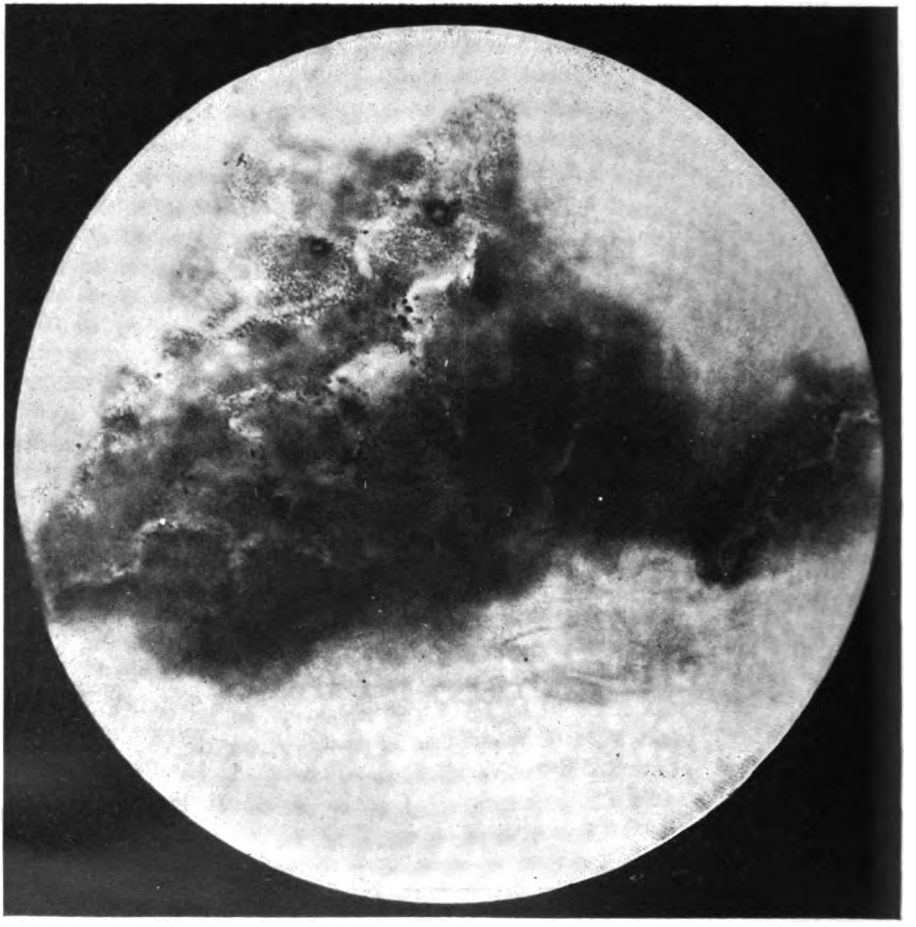

Fig. 15.

*Micrococcus nigrofaciens*, × 1000, in outer edge and in interior of integument. Gram + Eosin + KOH section of *Allorhina nitida*. Zeiss Oc. 4. Leitz Apo. Oil immers. 2 mm., Ap. 1.30.

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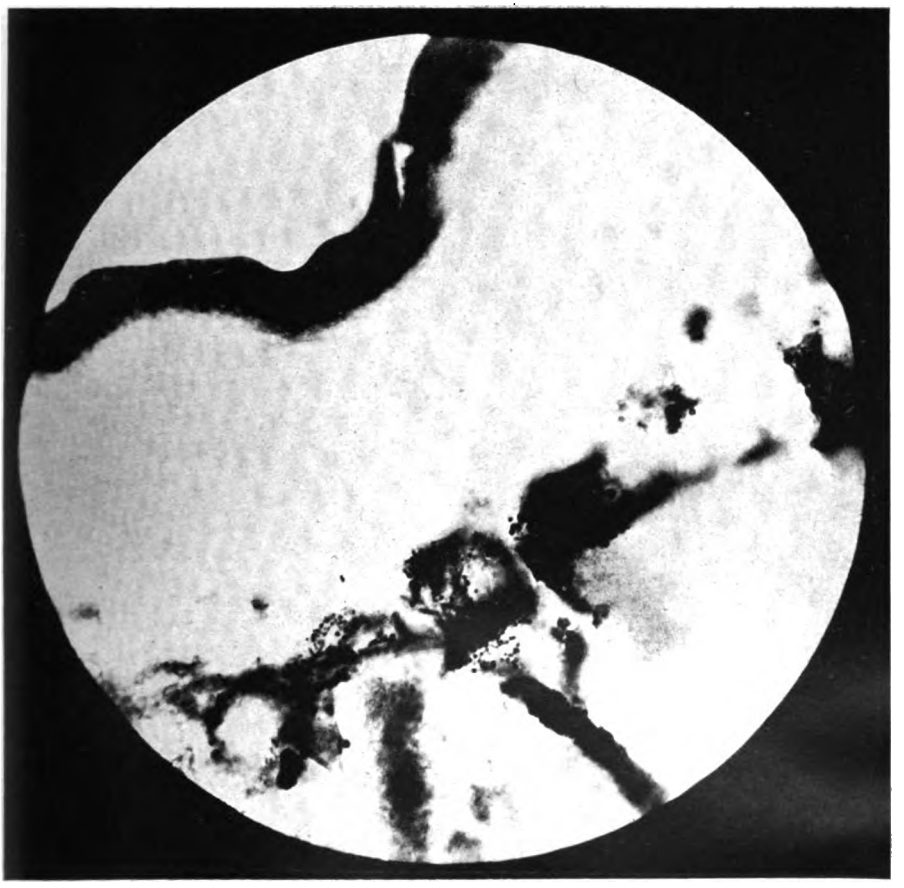

Fig. 16.

*Micrococcus nigrofaciens*, × 1000, in cells subnascent to the integument. Gram + Eosin + KOH section of *Allorhina nitida*. Zeiss Oc. 8. Leitz Apo. Oil immers. 2 mm., Ap. 1.30.

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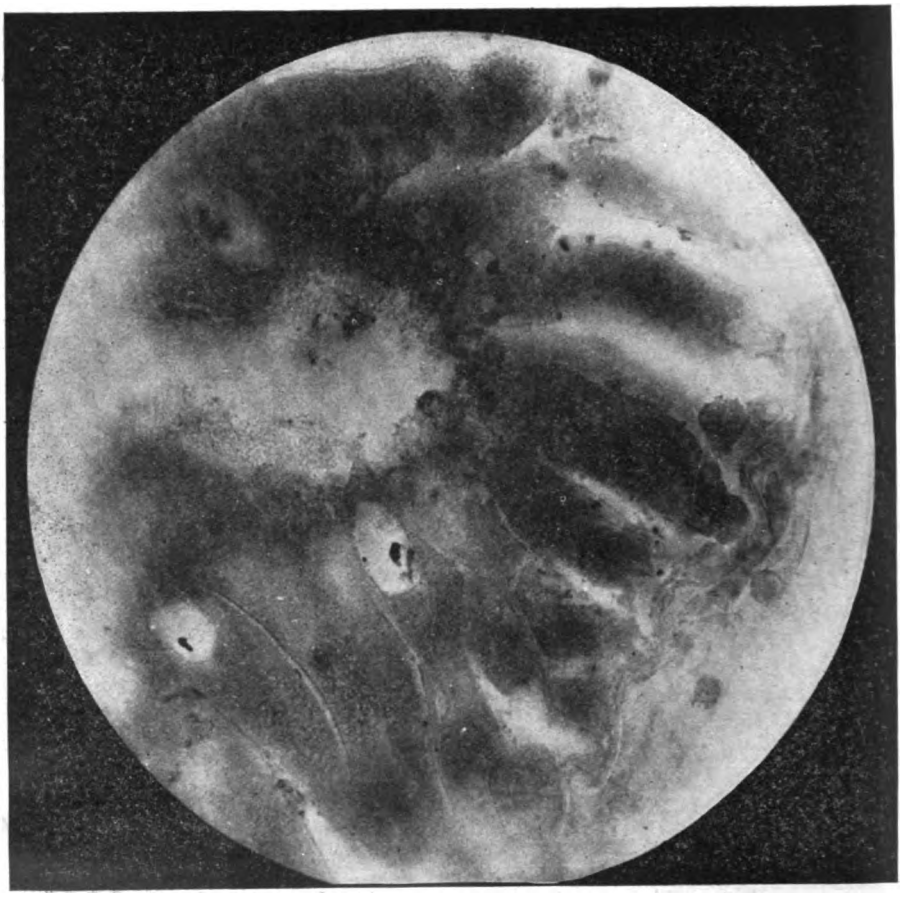

Fig. 17.

*Micrococcus nigrofaciens*, × 1000, in intestinal wall. Eosin and methylen blue. *Lachnosterna*. Zeiss Oc. 4. Leitz Apo. Oil immers. 2 mm., Ap. 1.30. Other material, nuclei of cells, dirt, etc., stains blue as well as the cocci.

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EFFECT OF THE MOISTURE CONTENT OF THE SOIL UPON DISEASED LARVÆ.

While moistening one lot of baked sterilized soil with sterile water, unintentionally an excessive amount of water was added. This soil was inoculated with a broth culture of the micrococcus as before and a slightly infected larva placed in it. This larva died within two days.

Other similar experiments were then performed to ascertain whether the excess of water was pertinent with regard to the time factor of the disease, i. e., whether the amount of water present in the soil, within certain limits, was not in direct proportion to the duration of life of the grub after infection.*

The following experiments seem conclusive: A larva having the middle left leg infected up near the body was placed in soil obtained from the garden near the laboratory; this soil has been free from "white grubs" as far as could be determined. Within 2 days the leg dropped off at the point of infection but during 14 days no further progress of the disease was noted. At this time an excess of water was added to the soil. Two days later the larva was found dead. The infection had progressed up into the body to some extent and the body contents seemed in a liquid condition.

A second larva, having the two front left legs off at the second joints and no other visible infection was placed in soil from the garden, as above. After 16 days sojourn in this soil, the larva was examined and the third leg on the same side was found to be infected at the tip; no other marks of infection were noted, nor had the infection apparently progressed in the other legs. The soil, at the end of 16 days, was then saturated with sterile water. Three days later, the larva was found dead, the last leg to be infected was found diseased where it joined the body and the infection had extended into the body whose contents were seemingly in a liquid condition as in the case of the first larva.

This phenomenon suggests several possibilities: (1) That this micrococcus is more virulent or finds more ready entrance into the body of the grub in the presence of excessive moisture; (2) that the same may be true with regard to the gas bacillus which is quite constantly associated with the micrococcus in diseased larvæ; (3) that the progress of the disease is augmented by the mere physical presence of an abnormal amount of water in the soil.

These hypotheses seem to be confirmed by a survey of the natural conditions which obtained during the summer of 1912. The farmers will remember the above mentioned season for its continuous rainfall. The official weather reports for this region do not show an especially marked increase in rainfall over that of other years but a glance at the data (19) shows the following conditions:

Although on but 14 days out of 31 in both July and August and 13 out of 30 in September, precipitation was recorded, in many cases this occurred several days in succession with cloudy days intervening, allowing of almost no evaporation on account of continual low temperatures, the mean for July being 69.6°, for August 65.7° and September 62.7° Fahr. This would produce a continuous, almost water-logged condition of some soils. A correlated theory is, that the evaporation at the surface of the soil, especially that due to growing plants, is an important and perhaps a predominant factor in prolonging cloudy and rainy periods. A lowering of temperature during these periods is due to the same causes (20).

*Dr. Britton (12) says: "The dry season seems to favor the increase and abundance of white grubs. Several such droughts in succession generally precede or at least accompany severe white grub injury."

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These conditions, seem to account, partially at least, for the fact that the larvæ which were sent in early in July showed but slight infection while those sent in the latter part of August and September were in a very badly diseased condition.

In comparison, infected larvæ existing in ordinarily moist soil in the laboratory lived many days, in fact many weeks and months without a marked progress of the infection. A few slightly infected larvæ lived a maximum of six months under laboratory conditions. Muscardine, pébrine and flachérie (all, caterpillar diseases) are similarly affected by wet weather. (21) The death of the larvæ subjected to excessive moisture may have been due, however, not to the micrococcus alone but to this organism supplemented by the gas-producing bacillus found also in the plates made from the infected portion of a larva. (See pp. 6, 7, 8 and 23). This organism is very vigorous in its activities, grows abundantly on all ordinary media but is favored by sugar media in which it produces acid and gas; it liquefies gelatin rapidly and grows equally well at 25°C. and 37°C. It is found to be the predominant organism in badly diseased or in dead larvæ showing putrefaction. (This organism seems very similar to the bacillus of septicemia, *B. septicus insectorum*, investigated by Krassilstschik, both culturally and in its apparent action on the larvæ. The etiological relation of the gas bacillus to the brown coloration of the diseased larvæ has not yet been studied extensively.

When a mixed culture of the micrococcus and bacillus in question was added to larva media (a healthy larva of the Southern U. S. May beetle, *Allorhina nitida*, placed in a test tube with distilled water and sterilized one hour in flowing steam) a putrid odor and gas production was first noted, later a black precipitate settled over the exposed parts of the larva. Whether this black precipitate bears any relation to the blackness of the infected areas in diseased larvæ has not been determined, but its occurrence in culture may be significant.

## PATHOGENICITY OF THE MICROCOCCUS TO OTHER FORMS OF ANIMAL LIFE.

### Angleworms.

The pathogenesis of the organisms in the mixed culture was determined in the case of angleworms for two reasons, to see whether the angleworm whose presence is desirable in soil would be disastrously affected by one or the other or the combination of both organisms, and should these organisms singly or in mixed culture be used for the extermination of the white grub, it would be of economic importance to know whether the culture used would be detrimental to this friend of the farmer.

Angleworms were placed in ordinarily moist soil artificially infected with the micrococcus and gas-bacillus; some were incised as in the white grub experiment preceding. As no signs of disease were noted after several days sojourn in the infected soil, sufficient water was added to it to produce a saturated condition. Two or three days later, both worms were found dead and liquefied inside; they decomposed entirely later and became slimy.

This experiment was repeated many times, always with the same results.

Microscopical examination of the slimy mass revealed a preponderance of bipolar-staining sporulating bacilli. These bacilli were isolated and found to produce the above results in pure culture, i. e., upon placing angleworms in sterile soil previously inoculated heavily with a broth culture of these bacilli, the angleworms were found liquefied and slimy within two days.

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These bacilli resembled very closely, morphologically and culturally, those introduced with the micrococcus.

The results produced upon the angleworms by inoculating sterile soil with the mixed culture were perhaps caused by the bacilli only, in the presence of an excess of water, or possibly by an association of the two organisms. No definite assertion can be made therefore as to which organism caused the death of the angleworms.

## The American Cockroach, *Periplaneta Americana.*

An attempt was made to determine the transmissability of the micrococcus infection to the large cockroach, *Periplaneta americana.*

Two live roaches of this species were placed in a sterile dish containing a piece of bread saturated with a broth culture of the micrococcus. After a sojourn of eleven days, the cockroaches were examined. Each roach was infected at the extremities of all six legs and the two hind legs of each were black and splitting or breaking off. One was nearly dead, showing life only by an occasional twitching of the legs. The antennæ and setæ of the latter were also apparently infected. By consulting the accompanying figure the point and progress of infection can be traced.

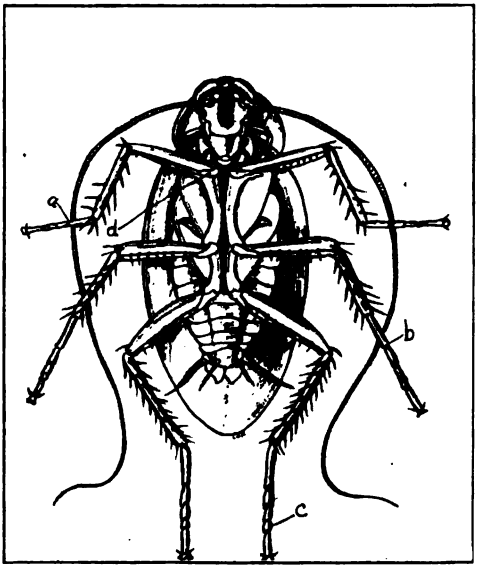


Fig. 18.

American cockroach, *Periplaneta americana.* Second roach in Fig. 1, Cir. 51, n. s. Bur. of Ent. U. S. Dept. of Agriculture, letters indicate place of infection. (See text).

The latter roach is designated as *A*, the former as *B*. *A* had both legs off at *a*, the right leg off at *b* and both at *c*. *B* had the left leg off at *a*, both at *b*, right leg off at *c* and at *d*.

*A* was placed in a sterile dish to see if the micrococcus could be recovered from the feces. Microscopic examination of smears of the feces stained

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with carbol-fuchsin showed myriads of organisms, micrococci were common, also sporulating bacteria.

One of the infected legs of *B* was ground up in a mortar, smears and plates were made. The micrococcus was demonstrated in both instances and isolated.

Two other roaches of this same species were treated in the same manner as *A* and *B*. One of these showed no infection after thirteen days, but a month later one leg was infected; the roach died a few days later. The other specimen was dead and decomposed so badly at the second examination that the presence or absence of infection could not be determined.

### Guinea Pigs and Rabbits.

Guinea pigs and rabbits injected subcutaneously and intraperitoneally with a salt solution suspension of the micrococcus showed no ill effects of the inoculation in any way.

#### DEMONSTRATION OF THE MICROCOCCUS IN SOIL.

Naturally infected soil, i. e., soil shipped in with the disease grubs was plated. Although this soil must have contained the infectious material, at the necessary dilutions used no micrococci were found. If the characteristic growth on agar plates will again be noted (See pp. 8–12) this perhaps will offer some explanation as to why the attempts to isolate the organism from soil were always unsuccessful.

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## PART II.

#### EXPERIMENTS WITH LARVÆ OF *ALLORHINA NITIDA*.

It was supposed that no other healthy larvæ could be obtained for experimentation but happily a few specimens of the larvæ of the Southern U. S. June beetle, *Allorhina nitida*, which are different genus of the same family as *Lachnosterna*, were obtained (Feb. 1913) through the kindness of Dr. Geo. D. Shafer of the Entomological Division of this Station. These particular specimens were obtained from South Carolina.

#### PATHOGENICITY TO LARVÆ OF *ALLORHINA NITIDA*.

To a layman, these larvæ have about the same general appearance as our common white grub, differing however in that the specimens evidently in the last period of the larval stage are much larger than those of the same stage in the *Lachnosterna*, have a wedge-shaped, light-brown chitinous plate on either side of the prothorax just above and in front of the prothoracic spiracles, crawl upon their backs instead of upon their venters, and have very much shorter and weaker legs but are much more active.

Disposition was made of the larvæ as follows: One was placed in a test tube to which was added distilled water, and sterilized an hour in flowing steam, inoculated with the micrococcus and bacillus and incubated at room temperature. One larva was placed in each of three deep culture dishes of sterile soil (sterilized in the hot-air oven at 160-170°C. for one hour) to which sterile water had been added.

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Two days later the three larvæ were examined and found to be active and healthy. At this time, a broth suspension of the micrococcus was added to one dish, of the gas-producing bacillus to the second dish and a mixed suspension of the bacillus and the micrococcus to the third, and in addition enough water to saturate the soil in each.

Twenty-four hours later, the first larva was found to have a marked infection on the chitinous plates on either side of the prothorax. The larva seemed to be less active. A second healthy larva was placed in this soil at this time.

The larva in the soil to which the gas-producing bacillus had been added was found dead, with no lesions.

The third larva was left in uninoculated soil for four days. Two days after inoculation with the two organisms, the larva was found alive, with a line of infection on the dorsal side of the last abdominal segment, the whole body was hard and the larva did not respond when irritated.

Two days after the first infection was noticed, the larva first placed in the soil containing the micrococci, was found to be infected in two additional places, near spiracles, and the healthy larva which had later been placed in this inoculated soil was also infected in one place. Twelve days after infection was noted in the first larva, a new area nearly 4 mm. in diameter near a spiracle and all but one of the legs was found infected. The larva seemed to be dead but upon washing off for the determination of additionally infected areas an occasional twitching of the legs was apparent. This was still noted twenty-four hours later but the larva was found dead within forty-eight hours. The second larva in this same container was found to have four or five small infections on the posterior of the abdomen and also on the tip of one of the legs. An examination of the larva four days after being placed in the soil with the mixed culture showed the right front leg off at the last joint before it joins the body, and the stump was characteristically black.

Seven days later, the larva was active but several very small infected areas were noted on both dorsal and ventral portions of the body. At this time the larva in question was placed in the soil containing the pure culture of the bacillus to see if the course of the disease would be hastened. Two days later the larva was still normally active so the soil was saturated with sterile water and reinfected with the gas-producing bacillus.

Five days after the second introduction of the gas-producing bacillus and the saturation of the soil, the larva was re-examined and found to be a little less active; the tip of all three left legs and of the middle right one were infected but the excess of water in the soil had apparently had no marked effect. The next day, however, the larva was found dead, twenty days after being introduced into inoculated soil.

Individual larvæ seem to vary greatly in their power of resistance to the micrococcus.

Two healthy larvæ obtained later were placed in soil mixed with sphagnum. This soil was made up of a mixture of soils kept in the laboratory which have been in a perfectly dry state for several years. Sufficient water was added and the soil and sphagnum mixed until the compound was of the plasticity of ordinary soil, then the larvæ were introduced. No especial precautions were used to prevent the entrance of microörganisms other than the specific micrococci.

Twelve days after being placed in the above soil mixture an examination of the larvæ was made and both showed several small but characteristic lesions.

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The chances for artificial infection were very slight; the soil *may have* contained the organisms; no experiments have been carried on to ascertain the effect of dessication upon the vitality of the micrococcus. This circumstance seems to emphasize the pathogenicity of the micrococcus for its host or perhaps the susceptibility of the larvæ of this species to infection even in the absence of abnormal amounts of water in the soil.

Since the above statement was made a consignment of six dozen larvæ of the species *Allorhina nitida* was received from North Carolina; out of this number only three showed the absence of infection and one of these three was dead. This *may* explain the occurrence of infection in the dried laboratory soil; the organisms may have been previously present upon or within the larvæ.

This occurrence seems to point to the distribution of this disease over a considerable portion of the United States and within quite a wide range of climate. Specimens sent in later (See p. 34) seem to confirm the almost ubiquitous presence of the micrococcus in soil. In a recent communication from Dr. R. H. Van Zwaluwenburg (Jan. 30, 1914) of the Porto Rico Agricultural Experiment Station at Mayaguez, he states that "As far as I know there are no diseased larvæ obtainable on the island; all we have collected are healthy." However, several shipments of larvæ from Porto Rico (March, 1914) have shown 100 per cent infected, more or less.

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Fig. 19.

*Micrococcus nigrofaciens*, × 1000, in a break in the integument. Eosin + Gram + KOH. *Allorhina nitida*. Zeiss Oc. 8. Leitz Apo. Oil immers. 2 mm. Ap. 1.30.

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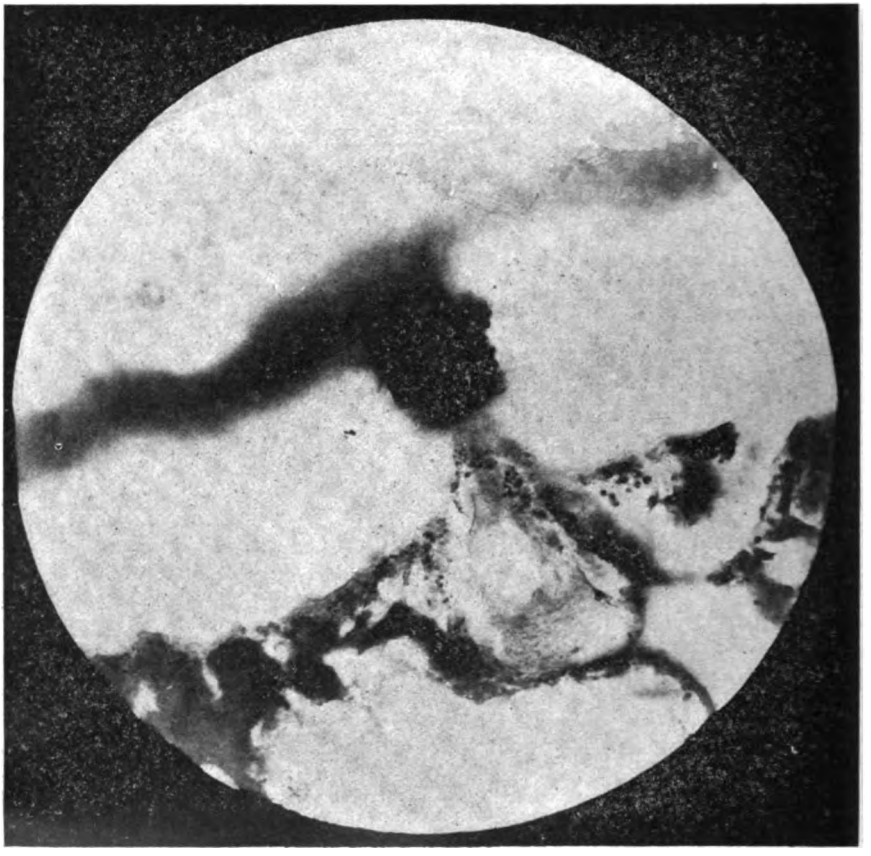

Fig. 20.

*Micrococcus nigrefaciens*, × 1000, in a hair follicle. Eosin+Gram+KOH. *Allorhina nitida*. Zeiss Oc. 4. Leitz Apo. Oil immers. 2 mm. Ap. 1.30.

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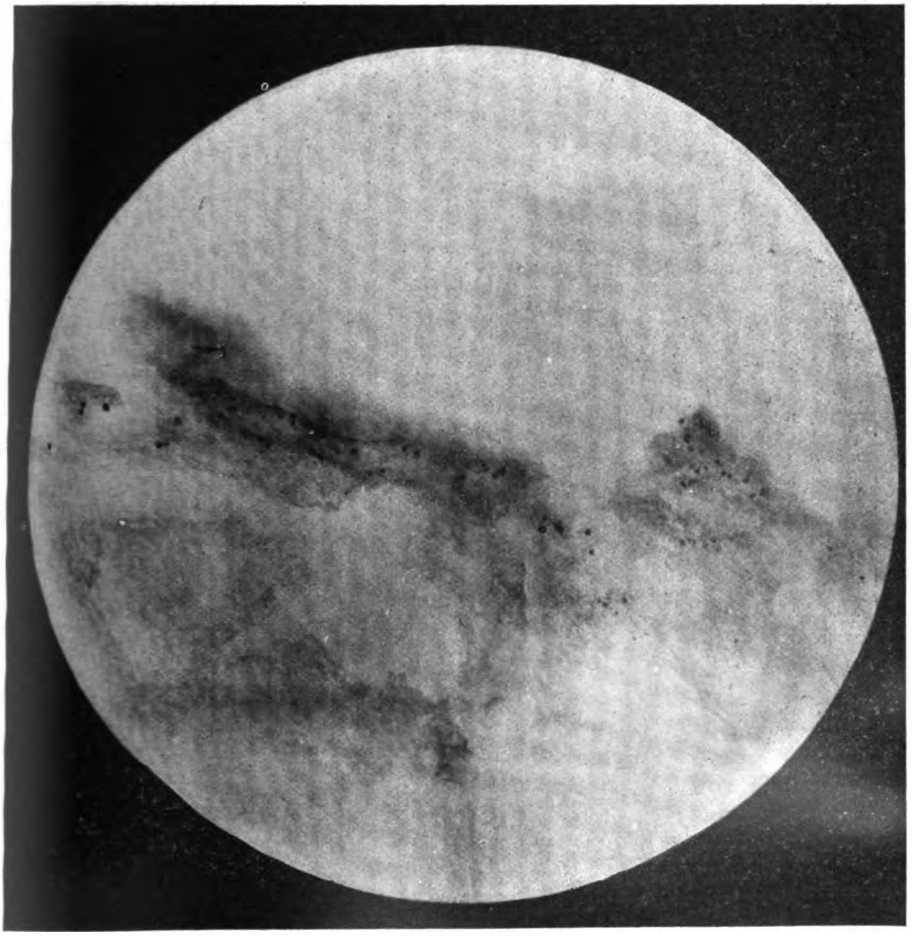

Fig. 21.

*Micrococcus nigrofaciens*, × 1000, in cells intermediate between integument and intestinal wall. Eosin +Gram +KOH. *Allorhina nitida*. Zeiss Oc. 4. Leitz Apo. Oil immers. 2 mm. Ap. 1.30.

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Fig. 22.

Pigmented cells, × 1000, in tissues underlying the integument. Stained with eosin alone. Zeiss Oc. 4. Leitz Apo. Oil immers. 2 mm. Ap. 1.30. These cells are dark brown in color, not taking the stain.

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MICROSCOPIC EXAMINATION OF DISEASED TISSUES OF A LARVA OF *ALLORHINA NITIDA*.

Microtome sections were made of the diseased portion of the first larva of this species which became infected. As the micrococcus is Gram-positive in culture, the Gram-Weigert method of staining tissues was used, counterstaining with eosin.

As before mentioned (p. 14) the micrococci found in the subnascent laminæ, and the surrounding tissue in the larva of *Lachnosterna* were a dark brown, almost black in color, the density of the color in the tissue diminishing with the distance from the apparent focus of infection. This diseased portion in all instances failed to stain; the dark brown color is due to a pigment which is evidently not soluble in any of the reagents used in staining, water, alcohol, anilin oil or xylol.

The only well known distinctly black pigment not derived from hemaglobin (22) (23) (24) produced in living tissues as a result of specific cell activity is an organic substance known as melanin, which is the cause of pigmentation in certain types of tumors and other pathological conditions. This metabolic pigment is autochthonous (25), i. e., found in the cells at the place of formation. Its elementary molecular composition according to Wells (26), is expressed by the following proportion, N:H:C=1:5:5, "probably being not a single substance of definite composition but including several related but different bodies." According to Schmiedeberg this pigment represents the *final product of a long series of metamorphoses of albumin* and in its formation may be compared to the development of humus. It is generally rich in sulphur in proportion to its carbon content, iron is oftentimes present but is not necessary to the formation of color (Ziegler).

Folsom (16) says that little is known as to the cause of the production of melanism in insects. Warmth is believed by some to be the most potent factor, others attribute it to moisture.

The pigment melanin is insoluble in water, alcohol, ether, chloroform, carbon bisulfid and weak acids but is quite readily dissolved in alkalies, strong acids or boiling alcohol, accordingly sections of the larval tissue were passed through an alcoholic solution of KOH before staining in order to remove the pigment should it be melanotic in character.

The caustic potash dissolved the pigment in the diseased areas allowing the micrococci and tissues surrounding to take the Gram-eosin stain. This method was checked by making a similar stain without previously passing the sections through KOH; the diseased areas and the micrococci showed the characteristic brownish black pigmentation.

In the "Gram+eosin+KOH" sections from the larva of the latter species, *Allorhina nitida*, micrococci staining blue were found in large numbers scattered through the inner cell structures, occasionally including the muscle fibers, also in masses in the hair follicles and occasionally in the outer chitinous layer of the integument (See Figs. 15, 16, 17).

In one of the "Gram+eosin−KOH" stained sections, occasional clusters of large, light-brown pigmented cells were found. (See Fig. 18) Nothing has been determined as to their nature.

Eosin was used alone as a stain, both with and without the use of KOH. In the absence of KOH, light yellowish to brown micrococci were found in the pigmented tissues. These were colorless when previously treated with KOH.

These results seem to establish this pigment as melanotic in character.

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Incision experiments with the larvæ of *Allorhina nitida* have resulted much more satisfactorily than with those of *Lachnosterna*. Results seem to lead to the conclusion that infection enters through some mechanical injury to the outer covering of the grub through attacks of other insects, or insect- or fungus-parasites. It is known that these larvæ attack each other, especially in confined spaces (14) and in this way infection may be introduced or spread. Several experiments seem to indicate that if such injuries are allowed to heal before the grub is subjected to infection, no lesion is found.

It has been previously mentioned (p. 28) that a consignment of six dozen *Allorhina nitida* larvæ showed only four per cent apparently healthy larvæ. The infection of the larvæ remaining was but slight in most cases, the general lesions being not more than 1-2 mm. in diameter; the larvæ were most active.

An interesting fact and one worthy of note was observed; after these larva had been left in soil in the laboratory for a month or so, earthen cells were found and when these were examined after a period of three months, it was found that a large percentage of these larvæ had developed into beetles. This corresponds to Krassilstschik's observations: "These (referring to the black spots) do not hinder the larvæ from being in the best state of health, from being transformed into a chrysalid, etc." (translation)

An infected larva of the genus *Lachnosterna* had also developed into a beetle.

From these occurrences, it may be safely concluded that infection with this micrococcus is not necessarily fatal to the completion of the life cycle of the June beetle in question. In addition, this fact seems to point strongly to the previous theory that the association of the two organisms found on plates made from badly diseased larvæ, is pertinent and perhaps necessary in the consideration of the fatality of the disease. Further studies are being made to determine if possible the pertinence of this association of the gas-producing bacillus and the micrococcus.

### GEOGRAPHIC DISTRIBUTION OF THE MICROCOCCUS.

Nearly all *Lachnosterna* larvæ received from the Southern portion of the lower peninsula of Michigan, were badly diseased. (Season of 1912)

*Allorhina nitida* larvæ received the spring of 1913 from North Carolina showed a large percentage (96 per cent) of diseased specimens. (Infection only slight, however).

*Lachnosterna* larvæ received during the fall of 1913 from Maryland, Michigan and Illinois through the courtesy of John J. Davis, Entomological Assistant of the U. S. Dept. of Agriculture, Lafayette, Indiana, almost without exception were infected, quite extensively in many cases.

It is evident that this organism has quite a wide distribution in the United States. Krassilstschik's observations lead to the conclusion that this micrococcus is found in Europe (France) also.

One hundred per cent of larvæ received from Porto Rico (March, 1914) were more or less infected.

Since this paper was given at the Michigan Academy of Science at Ann Arbor in April, 1913, requests have been received from the Porto Rico Experiment Station at Rio Piedras and also from Mayaguez, P. R. for cultures of the micrococcus with an idea toward using this as a means of combating the species of white grub which is so active in destroying the sugar cane on this island. No definite results have been obtained as yet from the use of these cultures.

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## SUMMARY AND CONCLUSIONS.

The June beetle larvæ or "white grubs" were prevalent during the season of 1912.

Their occurrence was accompanied by the appearance of a bacterial disease which is characterized by a blackening of the affected parts. The organism responsible for the infection is a micrococcus which was found microscopically in smears and in sections from diseased tissue and microscopically in almost pure culture on agar plates made from a diseased portion of a living grub. It is frequently accompanied by a gas-producing bacillus from which it is separated with difficulty.

The micrococcus exists in soil and is present in many soils in Michigan, Illinois, Maryland, North Carolina and most probably in other states and countries.

This microörganism grows well on ordinary media, but much better on larva media (gelatin, agar, broth and larva itself).

It stains well with ordinary aqueous-alcoholic stains, showing clearly the dividing cells; is not acid-fast but is Gram-positive.

The disease was successfully reproduced in a healthy larva of the same species by placing the larva in artificially infected soil, making an incision in the integument.

Parasitic insects or fungi, or the larvæ themselves may add materially to the chance of infection by producing a predisposition to the disease through mere mechanical injury.

The characteristic lesions were also produced in several healthy specimens of *Allorhina nitida* by merely placing them in water-soaked, sterilized soil to which a broth suspension of the micrococcus had been added.

Individual larvæ of one genus seem to vary greatly in their power of resistance to the micrococcus, the younger seeming to be the more susceptible. Larvæ of the genus *Lachnosterna* seem to be less resistant than those of the genus *Allorhina*.

Stained sections made from the diseased portions of larvæ demonstrate the micrococci unstained but dark brown in color imbedded in the laminæ (also unstained and brownish in color) of the integument. Large light-brown pigmented cells also are found within the body cavity. (See Fig. 22.)

This brownish-black color is due to a pigment presumably melanotic in character, most probably directly or indirectly produced by the activity of the bacterial cells within the larval tissue.

This micrococcus was found to be pathogenic to the cockroach *Periplaneta americana* also, the disease pursuing its course in much the same fashion as in the white grub, the infection however apparently limiting itself to the legs.

It cannot be definitely stated whether the micrococcus is pathogenic to angleworms.

Several unsuccessful attempts were made in isolating the micrococcus from naturally infected soil.

Excessively wet soil favors the progress of the disease. In fact this factor may be considered as probably the most important one concerned in the fatality of the infection.

Other organisms existent in the soil may cause an infection of the larvæ; a gas-producing bacillus (*B. septicus insectorum?* 14) found on the plate cultures seems to add materially to the fatality of the disease under certain conditions; this bacillus may be the primary invading organism.

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The micrococcus did not lose its pathogenicity after existing over a year under artificial cultivation.

It has not been possible as yet to try out this organism as a remedial measure for the destruction of the white grub. This effort will be made, however, at the earliest opportunity. The Porto Rico Experiment Station is taking up this matter in behalf of the sugar cane industry, cultures having been sent to Rio Piedras and Mayaguez for this purpose.

It seems from the definite results obtained by inoculating and saturating soil that this micrococcus may have a future field of usefulness in combating the white grub problem, *especially in cooperation with other parasitic diseases to which the larvæ are subject.*

Again, this micrococcus having the power of infecting larvæ of another genus (*Allorhina nitida*) and also insects in the adult form (*Periplaneta americana*) seems to suggest even wider possibilities, foremost of which is the control of other insect larva pests which work in the soil.

Many thanks are due Prof. R. H. Pettit and Dr. G. D. Shafer for giving access to the available literature and for may valuable suggestions. I am likewise very much indebted to the latter for furnishing species of the Southern U. S. June beetle.

Mr. John J. Davis, with the Government Bureau of Entomology has also kindly furnished *Lachnosterna* larvæ for investigation.

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TECHNICAL BULLETIN 19 JULY, 1914

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DIVISION OF CHEMISTRY

# SOIL ACIDITY.

BY

J. E. HARRIS.

EAST LANSING, MICHIGAN
1914

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# SOIL ACIDITY.

BY J. E. HARRIS.

## INTRODUCTORY AND HISTORICAL.

The problem of soil acidity has for a great many years been a serious one with the farmers of the eastern and middle western states, and is becoming more serious as the years go by. As the soil continues under cultivation, larger and larger areas are found to be sour or acid in character. When these soils are tested with blue litmus paper they very quickly turn it red. The peculiar thing about this reaction is that the test paper must be brought in direct contact with the soil particles for the change in color to take place. When the clear water solution of an acid soil is tested with litmus paper, it is usually found to be neutral. The soil on the other hand still gives the acid reaction. Whatever gives the acid reaction is, therefore, insoluble in water.

These soils possess another peculiar property. As already mentioned, if an acid soil be shaken with water, the solution obtained is neutral; but if we substitute, for the water, a solution of a neutral salt, such as potassium nitrate, a considerable quantity of free acid will be found in the resulting solution.

These phenomena have usually been explained on the ground that the soil contains complex organic acids, which are insoluble in water, making it necessary that the paper come in direct contact with them before the reaction can take place. In the case of the neutral salt a double decomposition is supposed to take place between the insoluble acid and salt, the base of the salt combining with the humic acid and the acid of the salt being set free.

It is a familiar fact that soils which show the above properties are not generally productive. The remedy for acidity in soils is well known. If the soil be treated with some form of lime, it is found to recover its productiveness provided other conditions are favorable. Most of the investigations of acid soils of late years have been directed toward developing methods for determining the degree of acidity or as it is sometimes called the "lime requirement." Many methods have been worked out but all are more or less unsatisfactory. Some of the more important methods will be briefly described.

Tacke[1] proposed treating the soil with calcium carbonate in an atmosphere of hydrogen and determining the amount of carbon dioxide evolved. The amount of lime equivalent to the liberated carbon dioxide represents the lime requirement. Süchting[2] modified Tacke's method as

[1] Chemiker Zeitung, 1897, 21, p. 174.
[2] Ztschr. Angew. Chem., 1908, p. 21, 151.

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follows: Ten to fifty grams of soil are mixed with water and about 0.4 gram of calcium carbonate (accurately weighed) added. The carbon dioxide liberated by the reaction is removed by a stream of hydrogen. Hydrochloric acid is then added and the additional carbon dioxide evolved is collected and titrated. The difference between the carbon dioxide liberated and the amount theoretically possible from the weight of calcium carbonate used, represents the degree of acidity of the soil.

Hollemann[1] determined the lime requirement by treating the soil with water charged with carbon dioxide, to dissolve the lime. If the amount thus obtained fell below a certain percentage, the application of lime was recommended.

Muntz[2] proposed shaking the soil with ammonium hydroxide and the need of lime was indicated by the color of the resulting solution.

Wheeler, Hartwell, and Sargent[3] proposed treating fifteen grams of the soil with 100 cc. of N/10 ammonium hydroxide and 100 cc. of distilled water. After allowing the mixture to stand for forty-two hours a test portion is drawn off and titrated with a definite amount of hydrochloric acid. After filtering off the precipitated humus, the solution is titrated back with ammonium hydroxide using coralline as an indicator. This gives the amount of ammonia taken up by the soil and therefore the acidity of the soil in terms of N/10 acid.

Veitch[4] treated samples of the soil with varying amounts of lime water to determine the amount just necessary to neutralize the acidity of the soil and leave it slightly alkaline.

Hopkins, Petit, and Knox[5] recommend shaking 100 grams of soil with 250 cc. of normal potassium nitrate solution, for three hours. After allowing the soil to settle, 125 cc. of the solution are drawn off and titrated with a standard sodium hydroxide solution. This treatment is repeated as long as the solutions are acid. The sum of the titrations gives a measure of the acidity of the soil.

Ramann[6] proposed a method similar to the above in which he used sodium acetate instead of potassium nitrate.

Albert[7] boils from 20 to 50 grams of soil with a known amount of lime and an excess of an ammonium salt. The ammonia liberated by the reaction is determined by collecting in a standard acid solution. The difference between the amount of ammonia liberated in this way and that theoretically possible represents the acidity of the soil.

Gregoire[8] makes use of Kjeldahl's reagent. This reagent consists of 55.3 grams of potassium iodide, 99.2 grams of sodium thiosulphate and 14.3 grams of potassium iodate per liter. A solution containing 17 grams of iodine and 25 grams of potassium iodide is used to titrate back the excess of sodium thiosulphate in the first solution. The soil is treated with Kjeldahl's reagent and the amount of iodine liberated furnishes a measure of the acidity of the soil. The iodine of course reacts with the sodium thiosulphate in the first solution and the amount of thiosulphate left is determined by titration with the second reagent.

[1] Landw. Versuchsstationen 1892, 41, p. 38.
[2] Encyclopedie Chemique, 4, pt 4, p. 18.
[3] Bulletin 62, Rhode Island Station.
[4] Jour. Amer. Chem. Soc., 1902, 24, p. 1120.
[5] Bulletin 73, U. S. Bureau of Chem.
[6] Bodenkunde, J. Springer, Berlin.
[7] Zeit. Angew. Chem. 1909 22 p 533.
[8] Bul. Soc. Chem. Belg. 1912, 26, p 336-342, 362-375, and 386-409.

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This method has an advantage over some of the other methods because it provides for the removal of the soluble acid as fast as it is formed, thus causing the reaction to go to completion. There is also a disadvantage in the use of Kjeldahl's reagent, because as the author points out in his article, other substances besides acids have the property of liberating iodine from the solution, as, for example, aluminum and ferrous sulphates. With this reagent, alkaline and neutral soils sometimes give an acid reaction.

Lipman[1] suggests a bacteriological method for the determination of soil acidity. This method is based on the fact that organisms of a certain type will not grow in bouillon in which the acidity exceeds 2%. The addition of the soil to be tested to a neutral medium will retard the growth of such organisms in direct proportion to its acidity.

In addition to the work that has been done on determining the degree of soil acidity, many investigations have been undertaken to determine the relation of soil acidity to the quantity of available phosphorus in the soil. As the result of the work of Wheeler,[2] Thorne,[3] Whitson[4] and Stoddart,[5] it has been shown that the content of this element is generally low in acid soils and largely unavailable for use by plants. Stoddart explains this by saying that acid soils convert any calcium phosphate that may be present into soluble compounds which are either washed out or are fixed in an insoluble form by the formation of iron and aluminum phosphates.

Until comparatively recently it has been the generally accepted theory that soils become acid through the accumulation of complex, insoluble organic acids. This theory had its beginning in 1826 when Sprengel,[6] by treating a soil with ammonium hydroxide and afterward neutralizing the solution with hydrochloric acid, found that a brown precipitate separated out to which he gave the name humic acid. The reactions of this substance toward other acids and various mineral salts were studied. In 1839 Berzelius[7] obtained two substances by treating a soil with an acid, one being soluble and the other insoluble in alkali. The first of these he considered identical with Sprengel's humic acid. To the second he gave the name, humin. Berzelius also showed that these two substances were similar to those obtained by Malaguti[8] by heating cane sugar in an open vessel with a solution consisting of one part of sulphuric acid and thirty parts of water, which, upon being analyzed gave an empirical formula of $C_2H_2O$. This agreed with Sprengel's analysis of humic acid as far as the carbon was concerned but was higher in oxygen and lower in hydrogen. Berzelius ascribed this lack of agreement to inaccuracies in analysis. Berzelius also discovered two other acids, crenic and apocrenic acids, which were found in certain iron-bearing mineral waters and were very similar in properties and composition to humic acid.

Mulder[9] found a fourth acid which he called ulmic acid. This differed

[1]Proc. A. O. A. C. 1911, Bureau of Chem. Bulletin 152.
[2]R. I. Station Report 1900, pp 293-327.
[3]Ohio Exp. Station Bulletin No. 159.
[4]Jour. Amer. Chem. Soc., 29, 1907, p 757.
[5]Jour. Ind. and Eng. Chem., 1, 1909, p 69.
[6]Archiv. fur die Gesamte Naturlehre, 1826, 8, p 145.
[7]Lehrbuch der Chemie, 3, Auflage, 8, p 389.
[8]Annalen der Phar., 1836, 7, p 52.
[9]Jour. fur Prok. Chem., 1840, 21, p 203.

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from the humic acid only in chemical composition, containing less carbon and more water. Corresponding to the humin of the humic acid, he discovered ulmin which like humin was insoluble in alkalies. He also obtained substances from sugar which he identified as ulmic acid and ulmin. These two substances could be changed by boiling into humic acid and humin. Sestini[1] found still another pair of substances which he called sacculmic acid and sacculmin.

Chemical formulae were worked out for all the above substances, though a great deal of variation was found in their composition, especially between those compounds obtained from sugar on the one hand and from soil on the other. For example, the substances obtained from soil contained nitrogen, silicic acid, phosphorus and other mineral constituents which were absent in the products obtained from sugar. It was at first supposed that these discrepancies were due to impurities which it was impossible to get rid of in the products obtained from the soil. However, in time, these variations caused chemists to wonder whether the differences were due simply to impurities or to an actual difference in the compounds themselves. Eggertz[2] analyzed several samples of humic acid obtained from soils and found that the carbon varied from 40.86% to 56.18%, hydrogen from 4.33% to 6.63%, phosphorus from 0.15% to 7.58% and so on for the several other constituents. As a result of these analyses many people became skeptical of the existence of any definite compounds of the nature of humic acid. Van Bemmelen[3] made the statement in 1888 that humus substances are not definite compounds at all and that the chemical formulae for humic acid, humin, ulmic acid, ulmin, etc., have no value whatever. He maintained that the humus substances are colloidal in nature and that the so-called humates are adsorption compounds.

The work of Eggertz, Van Bemmelen and others has caused chemists to seek a new theory for the explanation of the peculiar behavior of acid soils toward litmus and toward salt solutions. Linder and Picton[4] and later Whitney and Ober[5] have shown that when arsenic trisulphide in colloidal solution is precipitated by a solution of barium chloride, the precipitation is accompanied by the adsorption of a slight amount of barium and the setting free of a corresponding amount of hydrochloric acid. Cameron[6] has pointed out that certain substances have a selective adsorbing power. For example, metallic silver can be separated from a solution of silver nitrate by the selective adsorbing power of charcoal. Blue litmus will turn red if left in contact for a short time with moist, acid-free cotton. This phenomenon can be explained by ascribing to the cotton a selective adsorbing power for the base of the blue litmus salt, the base being adsorbed while the red acid dye remains on the paper. The action of acid soil toward litmus may be explained in exactly the same way. Also, in the action of the soil toward salt solutions, we may assume that the soil adsorbs the base in the same way that the arsenic trisulphide adsorbs the barium in Linder and

[1]Die Landwirt. Versuchsstationen, 1881, 26, p 285.
[2]Biedermann's Zent' für Agr. Chemie, 1888, 18, p 75.
[3]Die Landwirt. Versuchsstationen, 1888, 35, p 113.
[4]Jour. Chem. Soc., 1895, 67, p 63.
[5]Jour. Amer. Chem. Soc., 1901, 23, p 842.
[6]The Soil Solution, p 66, Chemical Publishing Co.

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Picton's experiment, leaving a corresponding amount of acid in solution. If an acid soil, for example, were treated with a solution of sodium chloride, it would adsorb a certain amount of sodium hydroxide leaving hydrocholoric acid in solution. The fact that there is so much colloidal matter in the soil makes this theory seem the more reasonable since, as mentioned above, Linder and Picton have shown that the coagulation of a negatively charged colloid by a salt is accompanied by the adsorption of the negatively charged ion. Coehn[1] has come to the conclusion that those colloids which have a lower dielectric constant than water will be charged negatively, while those having a higher dielectric constant will be charged positively. Since, in general, solids have a lower dielectric constant than water, suspension colloids, such as we have in soils, would adsorb the base when coagulated by a salt solution. This agrees with the facts set forth above.

In support of the adsorption theory as an explanation of soil acidity, Baumann and Gully,[2] in 1910, published the results of some experiments from which they conclude that the acid reaction of peat moss and of peat soils in general is caused by the colloidal matter in the coverings of the hyalin sphagnum cells. Tacke and Süchting,[3] on the other hand, maintain that acid soils produce certain reactions which can only be explained by the presence of a true acid, such as would be produced by the inversion of sugar and the liberation of hydrogen when brought in contact with iron. In a reply to this criticism, Gully[4] asserts that all the reactions mentioned by Tacke and Süchting can be produced without the presence of a true acid.

## EXPERIMENTAL

The acid reaction of the sand and clay soils of this country can hardly be ascribed to the presence of these hyalin cells and the experiments described in this paper were undertaken to determine, if possible, whether this acid reaction of upland soils is caused by the presence of humic acids or by adsorption of the bases by the colloidal matter present.

Experiment I. In Bulletin 107 of the Department of Agriculture,[5] a provisional method is given for the quantitative determination of acidity in soils. This method is based on the theory that when a soil is shaken with a neutral salt solution, the difficultly soluble humic acids enter into a double decomposition with the salt, setting free a soluble acid. The soil is shaken with one portion of salt solution after another until it no longer gives an acid solution. The soil is then found to be neutral to litmus and the total amount of acid set free is taken as a measure of the acidity of the soil. If the hypothesis upon which this theory is based furnishes the correct explanation for the action of the soil, then the total amount of acid liberated would be the same no matter what salt solution is used. On the other hand, if the action is due to selective adsorption on the part of the soil, we would expect the

[1] Wied. Ann. 1898, 64, p 217.
[2] Mitteilung der K. Bayr. Moorkulturanstalt, 1910, p 31-156.
[3] Landw. Jahrbucher, 1911, 41, p 717-754.
[4] Mitteilung der K. Bayr. Moorkulturanstalt, 1913, p 85.
[5] Loc. Cit.

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amount of adsorption to depend more or less on the salt used, since colloidal substances adsorb more of some bases than of others. To determine whether or not the same amount of acid is set free when different salt solutions are used, samples of an acid soil were treated with solutions of potassium nitrate, sodium acetate, and sodium chloride. The method of procedure was as follows: Two hundred and fifty cubic centimeters of the normal salt solution were added to 100 grams of soil and the whole allowed to stand with frequent shaking from two to three hours. The mixture was then centrifuged and 100 cc. of the clear solution drawn off and titrated with N/50 alkali from which the amount of alkali required to neutralize the total amount of solution was computed. The remainder of the solution was poured off from the soil and the treatment repeated until no more acid was liberated and the soil was no longer acid to litmus. The results as given in the following table show the amount of N/50 sodium hydroxide required to neutralize the acid liberated by each treatment of the soil with the neutral salts.

TABLE I.

| Number of treatment. | $KNO_3$. | $NaC_2H_3O_2$. | NaCl. |
|---|---|---|---|
| | c.c. | c.c. | c.c. |
| 1 | 41.0 | 98.0 | 27.3 |
| 2 | 8.7 | 32.1 | 9.3 |
| 3 | 5.4 | 23.2 | 6.4 |
| 4 | 3.7 | 17.2 | 3.9 |
| 5 | 3.2 | 14.5 | 3.3 |
| 6 | 2.8 | 13.0 | 2.6 |
| 7 | 2.2 | 12.0 | 2.2 |
| 8 | 1.9 | 11.3 | 1.8 |
| 9 | 1.6 | 11.0 | 1.8 |
| 10 | 1.3 | 10.7 | 1.6 |
| Total | 71.8 | 243.0 | 60.2 |

It is seen from the table that the greatest amount of acid is set free in the sodium acetate solution, the potassium nitrate coming next and the sodium chloride last. A large part of the variations observed is no doubt due to the difference in the strength of the acid set free, a much greater quantity of the weak acetic acid being set free than of the hydrochloric or nitric acids. We would expect some such variation as this whether the acid is set free through a double decomposition or through the adsorption of the base by the colloidal matter. However, if the acid is set free through a double decomposition, the amount should approach the same limit in every case, this limit corresponding to the amount of humic acid originally present in the soil. This, however, is not the case. Not only is a much greater amount of acid set free in the sodium acetate solution than in the potassium nitrate solution, but the ratio of the number of cubic centimeters set free in the former case to that in the latter becomes greater with each successive application. Thus we see that the ratio of the acid set free in the first application of sodium acetate to the corresponding number for the potassium nitrate solution is 2.39, while the ratio of the totals in the two cases is 3.38. The ratio in the case of the last application is 8.2. These values indicate that not only do we not get the same amount of

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acid liberated in the salt solutions, but that the difference in amounts becomes greater with each succeeding application of salt solution. Thus, we find that the facts do not coincide with the humic acid theory but do satisfy the conditions for selective adsorption. The above results also indicate that those methods for the quantitative determination of the acidity of the soil which depend upon the treatment of the soil with a neutral salt solution are of little value, unless the same reagent is used in the determination as is actually made use of in the field for correcting the acidity. The methods of Veitch and Süchting[1] should come closest to giving the true lime requirement of the soil, since the former employs lime water and the latter calcium carbonate as the reagent in the determination.

Experiments similar to those above were performed with other soils and always with the same result: the greatest amount of acid being set free in the sodium acetate solution, a very much smaller quantity in the potassium nitrate solution, and least of all in the sodium chloride solution.

Assuming for the time being that we do have selective adsorption on the part of the acid soils, how are we to explain the fact that all soils are not acid since all contain colloidal matter? Also why is it that soils which were originally alkaline or neutral come in time, after long cultivation to show acid properties? These questions may be easily answered in the light of the selective adsorption theory.

We may assume that in soils containing an excess of basic material, the colloidal matter will exist in a flocculated condition. Under conditions which favor a more or less rapid decomposition of the soil organic matter, certain acids will be formed, some of which, at least, will combine with the basic material (calcium carbonate) to form soluble salts and be eliminated from the soil through the drainage system. In addition some of the basic material will be removed by the crops and under the action of these two agencies the soil will, after a time, become deficient in basic material. The colloidal matter will become deflocculated and the soil will then adsorb the base from any neutral salt. If this be the manner in which soils become acid, it is probable that all the bases are not removed by the above process. The soil must obviously be able to retain some of the basic matter in the presence of very dilute acids, for, otherwise, the soil could not adsorb the base from a neutral salt and hold it in the presence of the acid thus set free. This being the case, it would seem probable that the acidity of a soil might be increased by treating it with a dilute acid to remove more of the basic material and then washing out the excess of acid with water.

Experiment II. One hundred grams of an acid soil were treated with N/20 sulphuric acid and allowed to stand about 24 hours, after which it was thrown onto a porcelain filter and washed until free from acid. For comparison, kaolin and finely ground quartz sand were treated in a similar manner. Each sample was shaken with 250 cc. of a normal solution of potassium nitrate, and 100 cc. portions were drawn off and titrated. Checks were run on the untreated samples in every case. The following table shows the amounts of N/50 sodium hydroxide required to neutralize the acid set free in each 100 cc. portion.

[1]Loc. Cit.

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TABLE II.

| | $KNO_3$. |
|---|---|
| | c.c. |
| Soil untreated | 1.0 |
| Soil treated with N/20 $H_2SO_4$ | 9.1 |
| Kaolin untreated | 0.0 |
| Kaolin treated with N/20 $H_2SO_4$ | 7.4 |
| Sand untreated | 0.0 |
| Sand treated with N/20 $H_2SO_4$ | 0.0 |

It will be seen that the acid reaction of the soil was very much increased by the treatment. The kaolin in its original state was perfectly neutral to litmus paper and neutral salt solutions but after the treatment with acid and its subsequent removal by washing with water, it was found to act similar in every respect to acid soils. It reddened blue litmus paper and when shaken with a solution of potassium nitrate, appreciable quantities of acid were set free as is shown in the above table. The finely divided sand gives no appreciable effect either before or after the treatment with acid.

Experiment III. To determine the effect of different acids on the soil and kaolin, several hundred grams of each of these substances were treated with solutions of N/20, HCl, $H_2SO_4$, $HC_2H_3O_2$, and $H_2C_2O_4$. After standing several hours the solutions were filtered off and the soils thoroughly washed with water until neutral and then dried.

Three 100 gram portions of each of the samples were prepared, one being treated with a normal solution of potassium nitrate, another with a normal solution of sodium acetate, and the third with a normal solution of sodium chloride. The results of this experiment, given in Table III, represent the amount of N/50 sodium hydroxide required to neutralize the acid set free in 100 cc. of solution.

TABLE III.

| | $KNO_3$. | $NaC_2H_3O_2$. | NaCl. |
|---|---|---|---|
| | c.c. | c.c. | c.c. |
| Soil untreated | 16.0 | 36.0 | 9.5 |
| Soil treated with N/20 $H_2SO_4$ | 24.3 | 45.0 | 19.0 |
| Soil treated with N/20 HCl | 23.5 | 46.5 | 18.0 |
| Soil treated with N/20 $H_2C_2O_4$ | 19.5 | 46.8 | 15.0 |
| Soil treated with N/20 $HC_2H_3O_2$ | 19.0 | 42.5 | 14.6 |
| Kaolin untreated | 0.0 | 0.0 | 0.0 |
| Kaolin treated with N/20 $H_2SO_4$ | 8.1 | 16.0 | 7.5 |
| Kaolin treated with N/20 HCl | 7.4 | 14.3 | 6.6 |
| Kaolin treated with N/20 $H_2C_2O_4$ | 4.6 | 11.8 | 4.1 |
| Kaolin treated with N/20 $HC_2H_3O_2$ | 6.4 | 13.4 | 5.5 |

It will be noticed from the above table that the effect of the acid in each case is to largely increase the adsorptive power of both the soil and kaolin, as was true in the preceding experiment. The amount of increase seems to be of about the same degree of magnitude with the different acids, although the two weaker acids, oxalic and acetic, give somewhat less effects than hydrochloric and sulphuric acids. It will also be seen that the three salt solutions stand in the same order with respect to the amount of acid set free in every case except with the untreated kaolin where there was no acid liberated by either of the salt

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solutions. This would indicate that the same cause is operating in the three cases to liberate acid. It is impossible to suppose that we have any humic acid, or for that matter any other true acid, in the case of the kaolin, and since the soil acts in every way like the kaolin, it is fair to assume that the cause of the action toward litmus and toward neutral salt solutions is similar in the two cases and is not due to the presence of humic acids.

There is another possible explanation for the action of the soil and kaolin when treated with an acid and then with a neutral salt solution. It is possible that they adsorb the acid with which they come in contact and hold it in an insoluble condition and that the effect of the salt solution is to set the acid free either by a double decomposition or by some physical action on the soil particles. For example, the soil may have a greater adsorptive power for the salt than for the acid, and in taking up the salt from the solution the acid is set free. Such an action would not be surprising since Van Bemmelen[1] has shown that a silica gel of the composition $SiO_2.4H_2O$ will retain aluminum chloride so tenaciously that it can not be washed out, but if the gel be brought into contact with a solution of potassium chloride, considerable quantities of the latter are adsorbed and a large part of the aluminum chloride goes into solution. If something of this sort happens in the case of the soil, it is likely that there would be a great variation in the amount of acid adsorbed if the concentration of the acid with which it is brought into contact were varied. If, on the other hand the effect of the acid is to neutralize the bases already present, rendering the soil capable of adsorbing greater quantities of the bases from the salt solutions with which it comes in contact, we would not expect any great variation until an acid so dilute is used that the soil could hold the base adsorbed in spite of the action of the acid. This would have to be an acid nearly as dilute as that found in the salt solution after being shaken with the soil.

Experiment IV. To determine the effect of concentration of the acid on the adsorptive power of the soil, samples were treated with solutions of N/2, N/5, N/20, N/40, and N/80 sulphuric acid. They were washed free of acid and treated with a normal solution of potassium nitrate, 100 cc. being removed and titrated as in the previous experiments. The results given in Table IV show the amount of N/50 sodium hydroxide required to neutralize the acid in 100 cc. The same experiment was carried out with kaolin.

TABLE IV.

| | Treated with | | | | | | |
|---|---|---|---|---|---|---|---|
| | Untreated. | N/2 $H_2SO_4$. | N/5 $H_2SO_4$. | N/10 $H_2SO_4$. | N/20 $H_2SO_4$. | N/4 $H_2SO_4$. | N/80 $H_2SO_4$. |
| | c.c. | c.c. | c.c. | c.c. | c.c. | c.c. | c.c. |
| Soil | 14.8 | 26.8 | 29.5 | 28.3 | 29.9 | 28.6 | 25.8 |
| Kaolin | 0.0 | 18.3 | 18.5 | 18.1 | 16.9 | 16.1 | 13.4 |

[1]Jour. Prakt. Chem. 2nd ser. Vol. 23, pp 324-349 and 379-395.

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The kaolin used in the above experiment was obtained from a different source than that of the preceding experiments. It will be seen from the above results that the concentration of the acid did not have any great effect on the adsorptive power of the soil. What variation there is seems to be due to a variation in the different samples of soil used, since it was impossible to get samples that were absolutely homogenous. This would indicate that there was no adsorption of the acid by the soil because there is no appreciable decrease in effect with decrease in concentration of the acid. It would seem that the effect of the acid is merely to neutralize the bases already adsorbed, thus increasing the capacity of the soil to adsorb the base from the salt solution. On the other hand, there is a marked falling off in effect with decrease of concentration in the case of the kaolin. The action of the acid in this case may have been to bring about a chemical change in the silicates rather than the neutralization of basic material.

That there is no adsorption of the acid by either the soil or the kaolin was further proved by treating samples of those substances with N/20 sulphuric acid, washing until practically free from soluble acids, and then treating with a normal potassium nitrate solution. If any sulphuric acid were adsorbed by the soil or kaolin, it would be set free by the action of the salt solution but on testing for the presence of the sulphate radical in the potassium nitrate solution, only a minute trace was found, the amount being sufficient to account for only a very small fraction of the acid found in the solution. Therefore, the action of the soil and of the kaolin on the salt solution could not have been caused by the presence of sulphuric acid held adsorbed by those substances.

Experiment V. This experiment was an attempt to prove that the soil actually adsorbs the base from a neutral salt solution. Samples of soil and kaolin were treated with N/20 hydrochloric acid, washed with water until free from acid and then treated with 250 cc. of normal barium chloride solution. After standing, the solutions were centrifuged and one hundred cubic centimeter portions removed and titrated with N/50 sodium hydroxide (table V column 1), after which the soil and kaolin were washed with water to remove the soluble barium salts and again treated with N/20 hydrochloric acid. One hundred cubic centimeters of this solution were drawn off and the barium determined by precipitation with sulphuric acid (table V column 2). Blanks were run to correct the weight of barium sulphate since it was found very difficult to wash out all of the barium salts and the amount of N/50 sodium hydroxide corresponding to the weight of barium sulphate calculated (table V column 3). After thoroughly washing the soil and kaolin they were treated a second time with a normal solution of barium chloride and the amount of free acid in 100 cc. determined by titrating with N/50 sodium hydroxide (table V column 4).

TABLE V.

| | N/50 NaOH in 1st $BaCl_2$ Solution. | Barium Sulfate. (Cor.) | N/50 NaOH calculated from weight of $BaSO_4$. | N/50 NaOH in 2nd $BaCl_2$ Solution. |
|---|---|---|---|---|
| | c.c. | gms. | c.c. | c.c. |
| Soil | 27.7 | 0.0631 | 26.3 | 30.4 |
| Kaolin | 12.5 | 0.0259 | 11.1 | 8.6 |

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The facts brought out by the preceding experiment can be satisfactorily explained on the basis of selective adsorption. By treating the soil with hydrochloric acid some of the adsorbed bases are converted into soluble salts and removed by washing. If, now, the soil be shaken with a solution of barium chloride it adsorbs barium hydroxide setting free a corresponding amount of hydrochloric acid. Upon treating the soil a second time with hydrochloric acid, the adsorbed barium will be converted into barium chloride which is easily removed. In the above experiment the amount of barium recovered corresponds almost quantatively to the amount of acid liberated by the previous treatment with barium chloride. After thoroughly removing the hydrochloric acid from the soil it will again adsorb barium hydroxide from a neutral solution of barium chloride in practically the same amount as originally.

If we accept the theory that the soil contains insoluble humic acids which enter into a double decomposition with the neutral salt the following reaction would represent the change

$$HA + BaCl_2 \rightarrow BaA + HCl$$

By far the greater part of the humic acid, HA, must be transformed by this process into the salt, BaA, because the first addition of a salt always gives a much greater quantity of acid than the second, and if the applications are continued until the soil is practically neutral, it is found that the acid set free in the first treatment forms a large percentage of the total. If we are to accept the law of mass action, this means that, for the action to go as far as it does, the salts of the humic acids must be either far more insoluble or far less dissociated than is the humic acid. To account for the recovery of the barium by the treatment with hydrochloric acid, the reverse action:

$$BaA + HCl \rightarrow BaCl_2 + HA$$

must take place, and since 95% of the barium taken up by the soil is recovered by this process, the reaction goes almost to completion in this reverse direction. For the reaction to go so nearly to completion in this direction, the humic acid must be far more insoluble or far less dissociated than the barium salts of these acids. But this conclusion is the exact reverse of that reached as a result of the first reaction. As a result of the above experiment we must conclude that the action of the soil towards neutral salt solutions and litmus paper is due to selective absorption and not to a double decomposition between the salt and humic acid.

The above conclusion has received further confirmation through some recent work by E. G. Parker. In a paper on "Selective Absorption by Soils",[1] Parker has shown that, if a soil is shaken with a solution of potassium chloride, the potassium ion is absorbed by the soil to a much greater extent than the chloride ion, and that there appears in the solution an amount of calcium, aluminum, magnesium and free acid that is almost exactly equivalent to the amount of potassium taken up by the soil. He also shows that, if a little sodium hydroxide is placed in the potassium chloride solution before treating the soil, no magnesium, cal-

[1] Jour. Agr'l. Research, 1, 1913, p 179.

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cium, aluminum or soluble acid is found in the solution, yet the amount of potassium in excess of chlorine absorbed by the soil is just about the same as in the case in which the sodium hydroxide was not present. This could not be the case if the acid in the first experiment were liberated through a double decomposition with the humic acids present. Parker explains the presence of magnesium, aluminum, etc., in the solution in which there was no sodium hydroxide by assuming that these substances are dissolved out by the acid set free through the selective absorption of the potassium ion, and this conclusion seems to be confirmed by the fact that he found none of these substances present when sodium hydroxide was added to the potassium chloride solution.

Experiment VI. In titrating the salt solutions with which the soil used in the preceding experiments had been treated, it was noticed that the addition of the alkali was accompanied by the separation of a light brown gelatinous precipitate. A similar precipitate was noticed in the corresponding experiments with the kaolin, except that in this case it was white. At first it was supposed that the precipitate in the case of the soil consisted at least in part of organic matter. However when tested, it was found to be wholly inorganic and to consist of a mixture of ferric and aluminum hydroxide. In the case of the kaolin, the precipitate was almost entirely aluminum hydroxide. These facts, together with the similarity of behavior of the soil and acid-treated kaolin raised the question as to what extent the selective adsorptive power of the soil is due to organic colloidal matter and to what extent it is due to inorganic colloidal matter. To determine this point, 100 grams of the same soil as used in experiment No. IV, were boiled for six or seven hours with concentrated sulphuric acid in a Kjeldahl flask. This treatment entirely destroyed the organic matter leaving a clean white sand. The soluble acid was washed out and the soil treated with a normal solution of potassium nitrate. A 100 cc. portion was drawn off and titrated. It was found that 29.1 cc. of N/50 sodium hydroxide were required to neutralize the acid set free in the salt solution. It will be noticed from Table IV, that the corresponding values for samples of this soil treated with acid varying in strength from N/20 to N/80 ranged from 25.8 to 29.9 cc. We have then a soil quite free from organic matter with a power to affect a salt solution in almost exactly the same degree as the soil with all the organic matter present.

The above experiment indicates that the behavior of the soil toward neutral salts is not due to the presence of insoluble organic acids, or even to the presence of organic matter at all but to inorganic compounds, probably hydrated silicates. This conclusion is in agreement with facts observed by many other investigators. As long ago as 1850, Way[1] succeeded in producing a silicate of sodium and aluminum that adsorbed ammonia from a water solution. This experiment is not strictly analogous to those described in this paper because we do not have colloidal matter breaking up a salt and setting free an acid. It does show however that substances of this nature may very readily, adsorb basic compounds. Dumont[2] has shown that clay, silicic acid, and ferric hydroxide will react with potassium carbonate and liberate carbon dioxide. Kaolin, however, was found to be practically inactive to-

[1]Jour. Roy. Agr'l. Soc., Vol. II, 1850.
[2]Compt. Rend. l' Acad. d. Sciences, 1906, p 345.

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ward the salt. The latter result is in agreement with the results of the writer since kaolin was found to be inactive toward a salt solution until it had been treated with an acid. Kozai[1] makes the statement that Daikuhaira had a soil under investigation which reacted acid toward neutral salt solutions though quite free from humus. No data are given in this article, but a publication embodying the results of the investigation is promised. The writer has searched the literature but has been unable to get any trace of the promised article.

## CONCLUSIONS

The results reported in the foregoing pages indicate that the reaction of so-called acid soils of the sandy loam type is one of selective adsorption by the soil of the basic constituents of the neutral salt solution. It is not due to a double decomposition with adsorbed acids or insoluble "humic acids."

Kaolin in its natural condition does not show the power of selective adsorption but after treatment with acids to remove the adsorbed bases it becomes capable of removing a corresponding quantity of base from a neutral salt solution.

The quantity of base adsorbed by a soil or by kaolin varies with different salt solution, thus rendering unreliable the results of any analytical method for determining the "lime requirement" of a soil unless the method employs the same material that is to be used in the field.

The "acidity" of soils of the type investigated probably arises from the formation of soluble salts through the interaction of weak acids ($C_2H_2O_4$, $CO_2$ etc.) in the soil solution and the basic material naturally held adsorbed by the soil and their subsequent removal by leaching. This leaves the soil free to adsorb more basic material from any source with which it may come in contact.

[1]Chem. Zeit., 1908, 32, p 1187.

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EXPERIMENT STATION.

BOTANICAL DEPARTMENT

# EXPERIMENTS ON THE CONTROL OF THE ROOT-KNOT NEMATODE

BY

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(In charge of Ginseng Disease Investigations in Michigan.)

EAST LANSING, MICHIGAN
1915

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# EXPERIMENTS ON THE CONTROL OF THE ROOT-KNOT NEMATODE.*

BY J. A. MC CLINTOCK,

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The root-knot nematode, *Heterodera radicicola,* (Greef) Müller, has proven to be a serious pest of many crops in the southern states, and in some of the western states it has caused considerable trouble on potatoes and sugar beets. In many of the northern states, this nematode has caused serious trouble on greenhouse crops and on such intensive garden crops as ginseng.

The life history of this parasite has been worked upon by (1) Atkinson†, (6) Stone & Smith, (2) Bessey, (3 and 4) Cobb, and control measures have been worked out for greenhouse conditions by Stone & Smith; while Bessey and (5) Rolfs have recommended rotations that tend to keep the root-knot nematode more or less under control in certain field crops. Much still remained to be worked out in the way of control measures for intensive crops like truck crops, ginseng, golden seal, etc.

For an account of the complete life history of the root-knot nematode see Bessey (2). Briefly it is as follows:

In about twenty-five days after the female enters a root, she has reached sexual maturity and begun to lay eggs. These eggs which are 85-98 microns in length by 34-40 microns in thickness, are surrounded, as laid, by a gelatinous substance which holds them together in a mass. In the case of firm, woody tissues, the eggs seldom reach the surface of the knot, but produce numerous larvæ which make their way to the surface and enter new roots. Where the root-knot is in softer tissues, as those of various herbaceous plants, the eggs are often forced through the tissues and cling in small masses to the surface of the knot. The number of eggs laid by a single female varies somewhat, but counts seem to show that it is between four and five hundred. In all cases where the number of eggs used in experiments is recorded, it is on the basis of four hundred eggs per egg mass, so in most cases the number of eggs treated probably ran over rather than under the number recorded. Under favorable conditions, the eggs probably begin to hatch within a few days after being laid, thus making the complete life cycle about thirty days under favorable conditions.

*The work upon which this paper is based was carried on under a cooperative agreement between the Bureau of Plant Industry and the Michigan Experiment Station, and in somewhat different form was accepted as a thesis for the degree of Master of Science in the Department of Plant Pathology, University of Wisconsin.

†The number with the author's name refers to the number of the article referred to as listed in the bibliography at the close of this paper.

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## FIELD EXPERIMENTS CONDUCTED IN MICHIGAN IN 1915.

As the chief work assigned to the author in Michigan was that of experiments on the control of the root-knot disease of ginseng, it was necessary to make a general survey of the various ginseng growing sections of the state, in order to select a suitable place for establishing a field laboratory. It was finally decided that a large garden located at Muskegon, Michigan, afforded the best opportunity for carrying on field experiments so the field laboratory was located there.

In order to exclude, as far as possible, any factors which might lead to errors in the results, it was decided that the plots used for experiments should be separated from the remaining soil. To accomplish this the plots of soil, seven by ten feet in extent, were enclosed with galvanized sheet iron thirty-six inches in width. The iron was set into the soil thirty inches, leaving six inches projecting above the surface to keep any surface soil from being washed into the plots after the experiments were started. The observation of nematodes three feet down in the soil has been recorded by Bessey (2) but the difficulty of obtaining iron more than thirty-six inches wide was so great as to preclude our placing it more than thirty inches in the soil. The edges, where the sheets of iron came together, were bent, interlocked and pounded tightly together to prevent the passage of anything at such places. To exclude the possibility of soil being carried onto the plots, by various animals passing through the garden, each plot was enclosed above ground with a three foot fense of chicken-wire netting, which came down so as to overlap the six inches of sheet iron above ground.

The plots, seven in number, were alternated with two foot paths, so as to cover the greater part of a strip of soil fourteen feet wide and seventy feet long. Two beds of badly nematode infested ginseng roots had been removed from this soil the fall previous, and no crop had been on the ground since. The soil, throughout the whole garden, is a loose, sandy loam, very highly fertilized with barnyard manure, making it an ideal place for the rapid multiplication and spread of the root-knot nematode.

Although the experiments of previous workers with chemical treatments of the soil for the eradication of *Heterodera radicicola* had given chiefly negative results, it was decided that a series of such treatments should be made to test the relative value of various chemicals, with the possibility of finding one that would be both effective and practical of application.

### CARBON BISULPHIDE TREATMENT.

As previous experiments by Bessey (2) had shown carbon bisulphide to be successful under field conditions, it was decided that one plot should be treated with this chemical exactly as recommended. On the afternoon of May 10, 1913, plot I was treated with carbon bisulphide as follows:—Holes were made in the soil at intervals of six to twelve inches, and varying in depth from six to eighteen inches. Liquid carbon bisulphide was poured into the holes at the rate of four ounces per square yard of soil, and the holes quickly plugged up by packing soil into them. Within half an hour after the treatment was made the air, in the vicinity of the plot, had a very strong odor of carbon bisulphide.

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and the odor was still quite noticeable the next morning after the treatment. From this it was concluded that the vapor had been passing up through the soil and out into the air for a period of about eighteen hours. Lettuce, tomato and cucumber plants are among those most readily attacked by the root-knot nematode; therefore, it was decided to use these plants to determine whether or not the soil treatments had eradicated the pest. May 14, 1913, lettuce seeds were planted in the carbon bisulphide treated plot, and also in the untreated soil about the plot to serve as a check on the treatment. May 31, 1913, the seeds planted May 14th had not produced many plants so the plot was replanted with lettuce, tomato and cucumber seeds. June 16, 1913, some of the larger lettuce plants were dug from the plot and their roots found to be somewhat affected with nematodes as shown by the small knots on them. Check plants dug from the soil outside of the plot were more seriously affected than those from the treated plot, thus showing that the nematodes had been reduced in numbers, but not eradicated by this carbon bisulphide treatment.

June 30, 1913, the rest of the plants were dug from the treated soil and the roots were found to be abundantly covered with knots, showing that the nematodes were increasing in numbers in the treated soil. August 16, 1913, this plot was retreated with carbon bisulphide as before, except that the surface of the soil was sprinkled with water and covered with burlap sacks, after the treatment, in an effort to keep the carbon bisulphide vapor from passing so rapidly from the soil out into the air. August 18th the sacks were removed from the surface of the plot and lettuce seed was planted in the treated soil. September 8th some of the lettuce plants were dug and examined but no knots were found on the roots. It was impossible to get further data on this plot during the rest of the season. In the summer of 1914 the author examined lettuce and cow pea plants from this plot and found nematodes on their roots.

### TOBACCO STEM TREATMENT.

The second plot was treated with tobacco stems. A wagon load of tobacco stems was collected from various cigar factories and taken to the garden. May 12, 1913, a layer of these stems over six inches in thickness was spread over all the soil of plot II. May 14, 1913, the stems were wet down with water. May 31, 1913, the layer of tobacco stems was removed from the plot and lettuce, tomato and cucumber seeds were planted in the treated soil, and also in the untreated soil outside the plot. June 16th some of the plants were dug from the treated soil and examined but no knots were found on the roots. June 30th lettuce, tomato and cucumber plants were dug from the treated soil and examined but no knots were found on their roots. August 11th, the author dug up lettuce, tomato and cucumber plants from the treated soil and found some small knots on their roots, showing that the nematodes had been reduced in numbers for a time, but not eradicated. The writer does not feel that such a treatment can be depended upon to give the desired results.



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### SULPHURIC ACID TREATMENT.

August 14, 1913, all of the remaining plants were dug from the second plot. The soil was then treated with a solution of one part of commercial sulphuric acid to eighty-five parts of water, using one-half gallon of this solution per square foot of soil. August 18th lettuce seed was planted in the treated soil. September 8th lettuce plants were dug from the plot and examined, but no knots were found on the roots. It was not possible to get further data on this plot during the rest of the season, but in the light of experiments performed later in the laboratory at the University of Wisconsin, it is probable that the sulphuric acid treatment did not eradicate the nematodes from the treated soil. In the summer of 1914 the writer examined plants from this plot and found root-knots on them.

### FORMALDEHYDE TREATMENTS.

It was decided that the third plot should be treated with formaldehyde. In 1912 some preliminary experiments along this line were started. During April, 1913, we had an opportunity of seeing the results of these soil treatments with a solution of one part of 40% formaldehyde to fifty parts of water. These treatments had not been successful in eradicating the nematodes from the treated soil; so we decided to double the strength by using 1-25 formaldehyde (1 part of 40% formaldehyde to 25 parts of water). May 12, 1913, plot III was treated with a 1-25 solution of formaldehyde, using one gallon to a square foot of soil. May 14th lettuce and cucumber seeds were planted in the treated soil to see if they would germinate and grow before the soil was free from formaldehyde gas. May 31st no lettuce or cucumber plants had come up from the seeds planted May 14th, so the plot was planted with lettuce, cucumber and tomato seeds. June 16, 1913, some of the plants were dug and examined, but no knots were found on the roots. June 30th, the author examined lettuce, tomato and cucumbers plants, but found no knots on their roots. August 11th, he dug up and examined lettuce, tomato and cucumber plants and found some small knots on their roots. This showed that the treatment with 1-25 formaldehyde had greatly reduced, for a time, the number of nematodes in the soil, but had not eradicated them.

August 13, 1913, the writer dug up all of the remaining plants from Plot III, respaded the soil, and then raked it so as to note and remove as far as possible, any pieces of roots which had been broken from the plants in digging. The soil was then retreated with a formaldehyde solution made up at the rate of one gallon of 40% formaldehyde to sixteen gallons of water, and applied at the rate of about one gallon of solution to a square foot of soil. August 14, 1913, lettuce seed was planted on this plot to see if it would grow before the formaldehyde gas was out of the soil. September 3, 1913, no lettuce plants had developed from the seed planted August 14th; so the plot was replanted with lettuce seed. September 8, 1913, no plants were up. No further data could be taken on this treatment during the rest of the season; therefore, we came to no definite conclusion relative to the value of this treatment. During the summer of 1914 plants from this plot were examined and nematodes found in the roots.

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### NAPHTHALINE TREATMENT.

As naphthaline was known to be more or less of a repellant to certain insects, it was suggested that it be given a trial. The original intention was to mix flake naphthaline with the soil. As it was not possible to obtain naphthaline in the flake form at the time it was desired to start the experiment, it was necessary to use it in the form of small balls, commonly called "moth balls." May 15, 1913, plot IV was treated as follows:—Holes were made in the soil at intervals of eight inches to one foot, and varying from six to twelve inches in depth. One or two naphthaline balls were dropped into each hole and the mouths of the holes then closed with soil packed into them. About one and one-half pounds of moth balls were used on the plot. May 31, 1913, the writer planted tomato and cucumber seeds in the naphthaline treated soil. June 16, 1913, some of the plants were dug and examined and found free from root-knots. June 30, 1913, the author examined tomato and cucumber plants from plot IV and found knots on their roots. This proved that the naphthaline treatment applied would not control the root-knot nematode.

### AMMONIA TREATMENT.

May 15, 1913, plot V was prepared for treatment as in plot IV, by making holes in the soil with a brass dibble. A small amount of 28% ammonia was poured into each hole, and then the holes were quickly plugged with soil. The ammonia gas soon penetrated the soil and gave the air in the vicinity of the plot a very strong odor. About three pounds of ammonia were used on this seven by ten foot plot. May 31, 1913, lettuce, tomato, and cucumber seeds were planted in the treated soil. June 16, 1913, some of the plants were dug up and knots found on their roots. This would seem to show that such an ammonia treatment had no effect on the nematodes in the treated soil. Later on in the season this plot was used for starting an experiment with ginseng roots apparently resistant to nematodes.

### "BLACK LEAF 40" TREATMENT.

It had been intended to make this and the following treatment at the same time the others were made, but they were delayed because we could not get the "Black Leaf 40" and the tobacco dust at that time. "Black Leaf 40," a commercial nicotine product made by the Kentucky Tobacco Products Company, has proven quite efficient as an insecticide for certain types of insects. As a result of its success as an insecticide, it was suggested for nematodes. Directions on the sealed can recommended the use of a one-half pound can of this concentrated nicotine product to thirty-four gallons of water, for all ordinary insects. This dilution was supposed to give not less than seven hundredths of one per cent nicotine. May 31, 1913, plot VI was treated with "Black Leaf 40" solution made up according to directions, and applied to the soil at the rate of one gallon per square foot. June 2, 1913, the writer planted lettuce, tomato and cucumber seeds in the treated soil. June 30, 1913, he dug up and examined lettuce and tomato plants from plot VI and found knots on their roots, thus showing that such a dilution of "Black Leaf 40" would not control root-knot nematodes.

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### TOBACCO DUST TREATMENT.

Tobacco dust, made by grinding tobacco stems into a fine powder, has proven quite efficient as an insecticide; so it was determined that it should be given a trial. June 2, 1913, twenty-five pounds of tobacco dust were spread over the surface of the soil in plot VII, and thoroughly raked into the soil. The plot was then thoroughly soaked with water. Later on in the day, lettuce and tomato seeds were planted in this plot. June 30, 1913, the author dug up and examined some of the plants from plot VII and found a few small knots on their roots. August 11, 1913, he examined plants from plot VII and found knots on their roots. This would seem to show that such an application of tobacco dust as was used, would not eradicate this nematode.

### KEROSENE TREATMENT.

August 11, 1913, all the plants from plot VI were dug up and the soil then treated with commercial kerosene, using ten gallons on the seven by ten foot plot. August 14, 1913,lettuce seed was planted in this plot. September 3, 1913, no plants had come up from the seed planted August 14th, so the plot was replanted with lettuce. September 8, 1913, no plants were up in this plot. No further data could be obtained on this treatment during the fall, so no conclusions could be drawn at that time. Plants from this plot were examined during the summer of 1914 and root-knots were found on them.

### GASOLINE TREATMENT.

August 11, 1913, the writer dug up and removed the rest of the plants from plot VII. The plot was then divided by setting a sheet of galvanized iron thirty-six inches wide, into the soil eighteen inches. This gave two plots five by seven feet in area. One of the plots was treated with commercial gasoline, by sprinkling one gallon over the surface of the soil. The other plot was treated in a similar manner except that three gallons of gasoline were used instead of one. August 14, 1913, lettuce seed was planted in both plots. September 8, 1913, the writer dug up and examined lettuce plants from both of the gasoline treated plots and found many knots on their roots. The heavy gasoline treatment appeared to have no advantage over the light treatment, and neither seemed to inhibit the development of the nematodes seriously.

### SUMMARY OF THE RESULTS OF THE FIELD TREATMENTS.

In all of the foregoing experiments the knots found on the roots of plants grown in the treated soils, were examined and dissected under a microscope to make sure of their true cause. In each case where complete data were obtainable they pointed to the conclusion that the treatment used could not be depended upon to eradicate the root-knot nematodes from the treated soil. In some cases the treatment succeeded in materially reducing the number of nematodes present in the soil, as shown by the longer periods that the plants grew in some plots before showing any knots on the roots. Treatments such as carbon bisulphide, tobacco stems or strong formaldehyde solution, which greatly reduce the number of nematodes in the soil for a month or so, might be of practical

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value in the case of some rapidly growing crop, which could be matured and removed before the nematodes again became numerous enough to materially injure the plants. In the case of a slow growing crop like ginseng, which remains in the soil from four to six years, any treatment which falls short of complete eradication is worthless, because a few nematodes left in the soil would completely restock it with their kind. In the course of a year or two they would be as serious as they were before the treatment was applied. In the light of these experiments, no chemical used could be recommended for the control of root-knot nematodes; furthermore, no exact explanation could be given as to just why the treatments did not eradicate the pest.

### THEORIES AS TO THE FAILURE OF THE FIELD TREATMENTS.

Various theories to explain the failure of the treatments were formulated, but none of them were backed by experimental data. It was thought possible that occasional nematodes more resistant than the average, were able to withstand the adverse conditions and that these resistant ones in time succeeded in restocking the soil, when conditions again became favorable for their growth and reproduction. A second theory was that nematodes deep down in the soil, where the treatments exerted little or no influence, came up and repopulated the treated soil after the effects of the treatments had sufficiently diminished. Another possibility was that the nematode eggs in the soil were of such a nature that they were able to resist the adverse conditions and remain dormant until favorable conditions allowed the young to come out into suitable environment for their development. As the second of the above theories did not appear to be of a nature to lend itself readily to investigation in the laboratory, it was decided to turn attention to the other two in an effort to determine what relation they might have to the failure of the soil treatments.

### LABORATORY EXPERIMENTS AT MADISON, WISCONSIN.

Early in October 1913, the experiments at the field laboratory were closed for the season, and laboratory work on various phases of the subject was begun in the greenhouses and laboratories of the Department of Plant Pathology of the University of Wisconsin. For some little time after arriving at Wisconsin, efforts were confined to fitting up experiments in the greenhouses, and to getting susceptible plants started so that there might be an abundant supply of nematodes to draw from for laboratory work. Considerable time was spent in various forms of laboratory experiments before suitable technique was worked out. An effort was made to get larvae free from the plant tissues by externally sterilizing knots from lettuce roots, and then placing them on plates of sterile agar. In no case did the writer succeed in obtaining any larvae free from the knots in this way. Failing in the above method, attempts were made to get the larvae by dissecting quantities of root-knots from lettuce and other plants. It was impossible in this way to get the larvae in sufficient numbers for the treatments it was desired to make.

Next was tried removing the roundish, pearly white female nematodes from small knots on the roots of various plants. It was thought that these females might produce eggs and larvae after being transferred to

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plates of agar. In most cases these females were not mature. When transferred to the plates of agar, they were soon overrun with colonies of bacteria and fungi, so that their development could not be followed. To avoid this contamination, it was tried treating the female nematodes as taken from the roots in various chemicals before transferring them to the plates of agar. Although in some cases they remained free from contamination after being transferred, in no case was success attained in getting larvæ in this way. Either their removal from the roots or the subsequent chemical treatments stopped the development of the female nematodes so that they never produced mature eggs.

The next effort was to obtain larvae by dissecting out mature or egg-laying females and egg masses from the older knots on the roots of various plants. Along with these females and egg masses were always some larvae that had hatched out within the knots from the first eggs laid by the females. Quantities of the egg masses from the root-knots were treated with various strengths of chemicals and then transferred to plates of agar. It was observed that the active larvae associated with the egg masses soon died when placed with the egg masses in the chemicals for external disinfection. This observation caused the writer to doubt the importance of our first theory; viz. that occasional larvae resisted the chemical treatments applied to the soil. The more observations that were made along this line, noting the apparent ease with which the larvae succumbed to weak chemicals, the more the writer was forced to the conclusion that the above mentioned theory was probably not the important factor in the failure of the strong chemical, soil treatments.

Other observations made about this time appeared to give more support to the theory that the mature eggs were the resistant stage. It was noted that in a few days after disinfecting mature females and egg masses, active larvae began to appear on the agar plates. As it was quite certain that no larvae had gone through the treatments alive, it was concluded that those found on the plates were larvae that had hatched from treated eggs. As a result of these observations, it was decided to discontinue for the time being, the efforts to determine the relative resistance of nematodes in the larval state, and to take up the egg resistance theory.

The first experiment which gave a possible explanation for the failure of the field experiments was begun December 23, 1913. A large quantity of mature female nematodes and egg masses was dissected from large knots on Primula roots and divided into seven lots of about an equal number of eggs. After being treated with the chemicals, the different lots were transferred to plates of sugar beet agar.

1. Placed the first lot in a solution made of one part of "Black Leaf 40" to 272 parts of water. This gave the same dilution as used in the field experiments.
2. Placed the second lot in full strength "Black Leaf 40" for a few minutes.
3. Placed the third lot in 1-1000 Hg $Cl_2$ for a few minutes.
4. Placed the fourth lot in 1-100 commercial 40% formaldehyde for a few minutes.
5. Placed the fifth lot in 1-10 solution of 40% formaldehyde for a few minutes.

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6. Placed the sixth lot in pure liquid carbon bisulphide for a few minutes.

7. Exposed the seventh lot to carbon bisulphide vapor, over the mouth of a bottle of liquid carbon bisulphide, until all the active larvae were killed. All of these treatments were made between 3:00 and 5:00 P. M., December 23, 1913. The results of the treatments are given in table I.

TABLE I.—ACTIVE LARVAE OBSERVED.

| Treatment made Dec. 23, 1913. | Dec. 24. | Dec. 25. | Dec. 26. | Dec. 27. | Dec. 28. | Dec. 31. |
|---|---|---|---|---|---|---|
| 1. "Black Leaf 40" 1-272 | Twenty | Abundant | Abundant | Abundant | Abundant | Active |
| 2. "Black Leaf 40" full strength | None | Four | One | Two | Active | Active |
| 3. $HgCl_2$ 1-1000 | None | None | None | None | None | None |
| 4. Formaldehyde 1-100 | None | None | None | None | None | None |
| 5. Formaldehyde 1-10 | None | None | None | None | None | None |
| 6. Carbon bisulph. liquid | Three | One | None | One | Active | Active |
| 7. Carbon bisulph. vapor | None | One | Two | Two | Active | Active |

January 2, 1914, the plates used above were all cleaned up. As the only means of detecting the presence of active larvae on the plates was by examining them under a microscope, it proved to be a rather difficult thing to locate all of the larvae after they had crawled away from the egg masses. Although the results of this experiment were not entirely conclusive either for or against the theory, it was decided to continue the work for the purpose of collecting data before coming to any definite conclusion.

EXPERIMENT II.—FORMALDEHYDE 1–100.

January 7, 1914, the writer dissected out about thirty egg masses from knots on Primula roots, and placed them in 1-100 solution of 40% formaldehyde for one and one-half hours, and then transferred them while still wet to a plate of potato agar. The results of this treatment are given in Table II.

TABLE II.—ACTIVE LARVAE OBSERVED.

| Treatment Jan. 7, 1914. | Jan. 8. | Jan. 9. | Jan. 10. | Jan. 12. | Jan. 14. | Jan. 19. | Jan. 23. |
|---|---|---|---|---|---|---|---|
| Formaldehyde 1-100 | None | None | One | Four | Active | Quiet | Quiet |

EXPERIMENT III.—FORMALDEHYDE 1–100 AND 1–10.

January 24, 1914, a large number of egg masses were dissected out and divided into two lots. Placed the first lot in 1-100 soltuion of 40% formaldehyde for ten minutes and then transferred it, while still wet, to a plate of potato agar. Placed the second lot in 1-10 solution of 40% formaldehyde for ten minutes and then, while still wet, transferred it to a plate of potato agar. The results of this experiment are given in Table III.

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TABLE III.—ACTIVE LARVAE OBSERVED.

| Treatment Jan. 24, 1914. | Jan. 26. | Jan. 27. | Jan. 28. | Jan. 29. | Jan. 30. | Feb. 2. | Feb. 7. |
|---|---|---|---|---|---|---|---|
| Formaldehyde 1-100..... | None | None | None | None | None | None | None |
| Formaldehyde 1-10..... | None | None | None | None | None | None | None |

EXPERIMENT IV.

January 26, 1914, dissected out a very large number of egg masses and divided them into eight lots. After treatment each lot was transferred to a plate of potato agar.

1. Treated the first lot in 3% hydrogen peroxide for 10 minutes.
2. Treated the second lot in 1-100 solution of 40% formaldehyde for 10 minutes.
3. Treated the third lot in 1-10 solution of 40% formaldehyde for 3 minutes.
4. Treated the fourth lot in 40% formaldehyde for 10 minutes.
5. Treated the fifth lot in 1-1000 $HgCl_2$ for 10 minutes.
6. Treated the sixth lot in saturated solution of $HgCl_2$ for a few minutes.
7. Treated the seventh lot in 20% copper sulphate for 30 minutes.
8. Treated the eighth lot in carbon bisulphide vapor for 1½ hours.

TABLE IV.—ACTIVE LARVAE OBSERVED.

| Treatment Jan. 26, 1914. | Jan. 27. | Jan. 28. | Jan. 29. | Jan. 30. | Jan. 31. | Feb. 1. | Feb. 3. | Feb. 4. | Feb. 5. |
|---|---|---|---|---|---|---|---|---|---|
| 1. Peroxide 3%..... | 15 | Abund. | Abund. | Abund. | Abund. | Abund. | Abund. | Abund. | Abund. |
| 2. Formaldehyde 1-100..... | None | None | None | None | None | None | None | None | None |
| 3. Formaldehyde 1-10..... | None | None | None | None | None | None | None | None | None |
| 4. Formaldehyde 40%..... | None | None | None | None | None | None | None | None | None |
| 5. $HgCl_2$ 1-1000..... | None | None | None | One | One | One | One | One | One |
| 6. $HgCl_2$ Sat. Sol..... | None | None | None | None | None | None | None | None | None |
| 7. $CuSO_4$ 20%..... | None | None | None | None | None | None | None | None | None |
| 8. Carbon bisulphide..... | None | None | None | None | None | None | None | None | None |

EXPERIMENT V.

February 2, 1914, dissected out a large number of egg masses from knots on tomato roots and divided them into eight lots. After treatment each lot was transferred to a plate of lima bean agar.

1. Treated the first lot in 3% hydrogen peroxide for 30 minutes.
2. Treated the second lot in 1-100 solution of 40% formaldehyde for 15 minutes.
3. Treated the third lot in 1-10 solution of 40% formaldehyde for 15 minutes.
4. Treated the fourth lot in 40% formaldehyde, full strength for 15 minutes.
5. Treated the fifth lot in 1-1000 Hg $Cl_2$ for 15 minutes.
6. Treated the sixth lot in a saturated solution of Hg $Cl_2$ for 30 minutes.
7. Treated the seventh lot in 20% copper sulphate for forty-five minutes.

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8. Treated the eighth lot in carbon bisulphide vapor for 17 hours. The results of this experiment are given in Table V.

TABLE V.—ACTIVE LARVAE OBSERVED.

| Treatment Feb. 2, 1914. | Feb. 3. | Feb. 4. | Feb. 5. | Feb. 6. | Feb. 7. | Feb. 9. | Feb. 10. |
|---|---|---|---|---|---|---|---|
| 1. Peroxide 3%..... | 7 | 70 | Many | Many | Many | Quiet | Appeared dead |
| 2. Formaldehyde 1-100.. | None | 1 | 4 | 21 | Abundant | Abundant | Abundant |
| 3. Formaldehyde 1-10... | None | None | None | None | None | None | None |
| 4. Formaldehyde 40%.. | None | None | None | None | None | None | None |
| 5. $HgCl_2$ 1-1000..... | 1 | 1 | 1 | 1 | 1 | None | None |
| 6. $HgCl_2$ sat. sol..... | None | None | None | None | None | None | None |
| 7. $CuSO_4$ 20%..... | None | 2 | 2 | 7 | Abundant | Quiet | Appeared dead |
| 8. Carbon bisul. vapor. | None | None | None | None | None | None | None |

February 10, 1914, all of the plates of the above series were cleaned up except the 1-100 solution of 40% formaldehyde. This plate was observed from time to time to see how long the larvae would remain alive. March 30, 1914, active larvae were observed.

EXPERIMENT VI.

February 28, 1914, dissected out many egg masses and divided them into four lots. After treatment, each lot was transferred to a plate of potato agar, and the plates sealed shut with paraffin.

1. Treated the first lot by rinsing it in boiled tap water.
2. Treated the second lot in 1-100 solution of 40% formaldehyde for 3 minutes.
3. Treated the third lot in 1-25 solution of 40% formaldehyde for 3 minutes.
4. Treated the fourth lot in 1-10 solution of 40% formaldehyde for 3 minutes. The results of these experiments are given in Table VI.

TABLE VI.—ACTIVE LARVAE OBSERVED.

| Treatment Feb. 28, 1914. | March 1. | March 2. | March 3. | March 4. | March 5. |
|---|---|---|---|---|---|
| 1. Boiled water..... | Larvae present | Larvae present | Larvae present | Larvae present | Larvae present |
| 2. Formaldehyde 1-100..... | None | None | None | None | None |
| 3. Formaldehyde 1-25..... | None | None | None | None | None |
| 4. Formaldehyde 1-10..... | None | None | None | None | None |

As the conditions under which these laboratory experiments were being conducted differed greatly from those in the field, it was concluded that possibly one or more of these factors was influencing the results, thus making the laboratory results very inconclusive. Perhaps the most obvious difference between the laboratory and the field experiments was the surroundings of the nematodes and eggs after treatment. In the field experiments the eggs were in the soil where plenty of air and moisture could get to them to dilute the various chemicals applied. In the laboratory experiments the eggs were enclosed in petri dishes which tended to keep out the air and moisture, and to keep in the volatile chemicals. This was especially true when the plates were sealed with paraffin. If petri dishes did act as an important factor in causing the chemicals to in-

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hibit nematode egg development, it was thought that this influence might be even greater if the containing vessel were smaller and more tightly sealed. To test this point, we decided to run a series of treatments in culture slides instead of petri dishes.

### EXPERIMENT VII.

March 7, 1914, dissected out a large number of egg masses from infested roots and divided them into eleven lots of about 3,000 eggs each. After treatment each lot was transferred to a cover glass and sealed down over a culture slide.

1, 2 and 3. The first three lots were rinsed in sterile water and served as checks on the treatments.

4. Treated the fourth lot in 3% hydrogen peroxide for a short time.

5. Treated the fifth lot in 1-100 solution of 40% formaldehyde for a short time.

6. Treated the sixth lot in 1-25 solution of 40% formaldehyde for a short time.

7. Treated the seventh lot in 1-10 solution of 40% formaldehyde for a short time.

8. Treated the eighth lot in 40% formaldehyde for a short time.

9. Treated the ninth lot in 1-1000 Hg $Cl_2$ for a short time.

10. Treated the tenth lot in pure liquid carbon bisulphide for a short time.

11. Placed the eleventh lot on a cover-glass and exposed it to carbon bisulphide vapor for ten minutes.

The results of these experiments are given in table VII.

TABLE VII.—ACTIVE LARVAE OBSERVED.

| Treatment March 7, 1914. | March 8. | March 9. | March 10. | March 11. | March 12. | March 13. |
|---|---|---|---|---|---|---|
| 1. Sterile water | Very many | Very many | Very many | Very many | Very many | Discontinued |
| 2. Sterile water | Very many | Very many | Very many | Very many | Very many | Discontinued |
| 3. Sterile water | Very many | Very many | Very many | Very many | Very many | Discontinued |
| 4. Peroxide 3% | Very many | Very many | All quiet | Quiet | Quiet | Discontinued |
| 5. Formaldehyde 1-100 | 14 | None | None | None | None | Discontinued |
| 6. Formaldehyde 1-25 | None | None | None | None | None | Discontinued |
| 7. Formaldehyde 1-10 | None | None | None | None | None | Discontinued |
| 8. Formaldehyde 40% | None | None | None | None | None | Discontinued |
| 9. $HgCl_2$ 1-1000 | Very many | Very many | Used for a | culturing ex | periment. | |
| 10. Carbon bisul. liq | None | None | None | None | None | Discontinued |
| 11. Carbon bisul. vapor | One | None | Two | None | None | Discontinued |

With the exception of the 1-1000 Hg. $Cl_2$ treatment, the various chemicals all produced more or less of an inhibitory effect on the eggs. And, even where the eggs did hatch, as in the 1-100 formaldehyde and the carbon bisulphide vapor treatment, the larvæ soon died. From this latter fact, it would appear that chemicals were still present in the sealed culture slides to such an extent as to be intolerable to the larvae. The large numbers of larvae that hatched from eggs in the check slides would seem to show that the chemicals were exerting a great influence. This and the previous experiments with closed vessels pointed quite strongly toward the surroundings as an important factor in our laboratory experiments.

In order to see whether the exception, in the case of the 1-1000 Hg $Cl_2$

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treatment of our last experiment, was a normal one, it was decided to repeat this part of the experiment.

EXPERIMENT VIII.

March 9, 1914, dissected out a number of egg masses and placed them in 1-1000 Hg $Cl_2$ for two minutes. The egg masses were then transferred to drops of agar on four cover glasses, and sealed down over four culture slides. The results of this experiment are given in Table VIII.

TABLE VIII.—ACTIVE LARVAE FOUND.

| Treatment March 9, 1914. | March 10. | March 11. | March 12. | March 13. |
|---|---|---|---|---|
| $HgCl_2$ 1-1000 | Very many | Very many | Abundant | All quiet |
| $HgCl_2$ 1-1000 | Very many | Abundant | Abundant | All quiet |
| $HgCl_2$ 1-1000 | Very many | Used for c | ulturing expe | riment. |
| $HgCl_2$ 1-1000 | Very many | Used for c | ulturing expe | riment. |

The results of this experiment appeared to verify those of the previous experiment, and to show that a short exposure to 1-1000 Hg $Cl_2$ does not keep the nematode eggs from hatching.

As it now seemed probable that the various chemicals exerted an inhibitory effect in closed vessels, it was decided that data should next be obtained on treatments conducted under conditions more nearly like those present in the soil of the field experiments. To accomplish this, the egg masses were placed after treatment in tubes of agar, closed only by cotton plugs. A synthetic agar medium was prepared by adding one and two-tenths per cent of powdered agar and one per cent of glucose to Pfeffer's nutrient plant solution. This on being sterilized and cooled, solidified into a solid medium, through which one could easily see. A number of tubes of this medium were prepared, using about ten c. c. to a tube.

EXPERIMENT IX.

March 14, 1914, dissected out a large number of egg masses from root-knots and divided them into twelve lots. After treatment, each lot was transferred to a tube of synthetic agar while it was still wet with the solution in which it had been treated.

1. Placed the first lot in 1-100 solution of 40% formaldehyde for a few minutes.
2. Placed the second lot in 1-25 solution of 40% formaldehyde for a few minutes.
3. Placed the third lot in 1-10 solution of 40% formaldehyde for a few minutes.
4. Placed the fourth lot in full strength 40% formaldehyde for a few minutes.
5. Placed the fifth lot in 1-500 Hg $Cl_2$ for a few minutes.
6. Placed the sixth lot in 1-200 Hg $Cl_2$ for a few minutes.
7. Placed the seventh lot in 1-100 Hg $Cl_2$ for a few minutes.
8. Placed the eighth lot in full strength "Black Leaf 40" for a short time.
9. Placed the ninth lot in full strength lime-sulfur, 31-32° B., for a few minutes.

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10. Placed the tenth lot in the same lime-sulfur as the ninth lot. After being in this solution for a few minutes, the egg masses were transferred to a drop of synthetic agar on a cover glass and sealed down over a culture slide instead of being placed in a tube of synthetic agar.

11. Placed the eleventh lot in full strength commercial sulphuric acid for a few minutes, and then transferred it to a slide of agar.

12. Placed the twelfth lot in 1-100 sulphuric acid for a few minutes. The results of this experiment are given in Table IX.

TABLE IX.—ACTIVE LARVAE OBSERVED.

| Treatment March 14, 1914. | Vessel No. of eggs used. | Mar. 15. | Mar. 16. | Mar. 17. | Mar. 18. | Mar. 20. | Mar. 22. | Mar. 24. |
|---|---|---|---|---|---|---|---|---|
| 1. Formaldehyde 1-100 | Tube 2000 | Abund. | Abund. | Abund. | Abund. | Abund. | Abund. | Abund. |
| 2. Formaldehyde 1-25 | Tube 3000 | None | Abund. | Abund. | Abund. | Abund. | Abund. | None active |
| 3. Formaldehyde 1-10 | Tube 3000 | One | Abund. | Abund. | Abund. | Very many | Very many | Very many |
| 4. Formaldehyde 40% | Tube 3000 | None | None | None | ..... | Two | Abund. | Very many |
| 5. $HgCl_2$ 1-500 | Tube 3500 | Very many | Very many | Very many | ..... | Very many | Very many | Many |
| 6. $HgCl_2$ 1-200 | Tube 2000 | Very many | Very many | Very many | ..... | Very many | Very many | ..... |
| 7. $HgCl_2$ 1-100 | Tube 2000 | Many | Many | Many | ..... | Many | Many | Many |
| 8. "Blk Lf. 40" full strength | Tube 3000 | Very many | Very many | Very many | ..... | Very many | Very many | None active |
| 9. Lime sul. full strength | Tube 3000 | One | Abund. | ..... | ..... | Abund. | ..... | None active |
| 10. Lime sul. full strength | Slide 3000 | None | None | None | None | None | ..... | None |
| 11. $H_2SO_4$ full strength | Slide 3000 | None | None | None | None | None | ..... | None |
| 12. $H_2SO_4$ 1-100 | Slide 3000 | None | None | None | None | None | ..... | None |

The results of this experiment as a whole, are so different from those of any of the previous tests that one is strengthened in the opinion that the containing vessel must have been a factor influencing the results. From the table, it will be noted that the treatments which allowed little or no hatching were those where sealed slides were used instead of test tubes. The lime-sulfur treatments give a good comparison of the difference due to the vessel used, because all other conditions were about the same. By referring to Experiment IX, it will be seen that the egg masses were all subjected to the same treatment with lime-sulfur, and then 3,000 eggs were placed in a tube of synthetic agar and 3,000 were placed on a drop of synthetic agar and sealed down over a hollow slide. Abundant larvae hatched from the eggs in the tube, while none hatched from an equal number of eggs in a culture slide. The amount of agar used might be considered as an important factor in bringing out the difference in the result, but by referring to the earlier experiments, it will be seen that where one tube, ten c. c., of agar was spread out over a plate, there was about the same inhibitory effect as in the sealed slide with one drop of agar.

This comparison of the type of vessel used was made for the purpose of trying to account for the great difference between the results obtained in the early experiments and those of later trials. In the early ones was

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noted a large per cent of inhibition of hatching, while in the later experiments, there was almost no inhibition from treatments with the same, and also with much stronger chemicals. In order to get further data on the inhibitory power of sulphuric acid, as compared with the other chemicals used, it was decided to repeat this treatment, using tubes of agar instead of slides.

EXPERIMENT X.

March 16, 1914, dissected out a large number of egg masses and divided them into three lots. These lots were treated for a few minutes in 1-100 $H_2SO_4$, 1-50$H_2SO_4$, and 1-25 $H_2SO_4$, respectively, and then transferred, while still wet, to three tubes of synthetic agar. The results of this experiment are recorded in Table X.

TABLE X.—ACTIVE LARVAE OBSERVED.

| Treatment March 16, 1914. | Number of eggs used. | March 17. | March 19. | March 20. |
|---|---|---|---|---|
| $H_2SO_4$ 1-100 | 5000 | Abundant | Abundant | Abundant |
| $H_2SO_4$ 1-50 | 5000 | Abundant | Very many | Very many |
| $H_2SO_4$ 1-25 | 5000 | Very many | Very many | Very many |

The results of this experiment would seem to show that even quite strong sulphuric acid solutions have no more of an inhibiting power than the other chemicals used, when the conditions are made the same.

EXPERIMENT XI.

This experiment was made for the purpose of determining the relative value of carbon bisulphide. March 20, 1914, about twelve thousand eggs were dissected out from knots on lettuce, squash and tomato roots, and divided into two lots of six thousand eggs each. The first lot was placed in pure liquid carbon bisulphide for a few minutes, and then transferred, while still wet, to a tube of synthetic agar. The second lot was placed on a hollow slide, and the slide was then inverted over the mouth of a bottle of carbon bisulphide. After being exposed to the strong vapor for twenty minutes, the egg masses were transferred from the slide to a tube of synthetic agar. The results of this experiment are given in Table XI.

TABLE XI.—ACTIVE LARVAE OBSERVED.

| Treatment March 20, 1914. | Number of eggs used. | March 21. | March 22. | March 25. |
|---|---|---|---|---|
| Liquid Carbon bisulphide | 6000 | Twelve | Abundant | Abundant |
| Vaporized Carbon bisulphide | 6000 | Many | Many | Abundant |

From these results it was concluded that treatments with carbon bisulphide, such as the above, do not materially inhibit the hatching of the nematode eggs.

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In all of those experiments with tubes of media, the synthetic agar was used. This medium gave a substratum as nearly like that of the soil as could be obtained and still have it clear enough to examine under a microscope, to determine the presence of larvæ. One of the questions that come to mind in the use of this synthetic medium, was that of the possible effect of the various salts of the medium on the chemicals used in the treatments. Did not these various salts tend to act on certain of the chemicals so as to make them lose their power to inhibit the hatching of the nematode eggs? If this occurred in the synthetic medium, one might conceive that it also occurred in the soil and thus might partially account for the failure of certain field experiments. To obtain data on this point, it was decided to run a series of treatments on a medium as free from these various nutrient salts as could be obtained. The best medium that could be devised for this purpose was a plain agar made of distilled water stiffened up with 1.5% of powdered agar. A number of tubes of this medium were made, using about ten c. c. to a tube.

EXPERIMENT XII.

March 21, 1914, a large quantity of eggs was dissected from knots on roots of lettuce and squash plants, and divided into twelve lots. After treatment each lot was transferred to a tube of plain agar.

1. Placed the first lot, of 3000 eggs, in liquid carbon bisulphide for a few minutes.
2. Placed the second lot, of 5000 eggs, on a cover glass and inverted it over the mouth of a bottle of carbon bisulphide for six and one-quarter hours. On removal from the bottle the egg masses were found to be very dry and hard.
3. Placed the third lot, of 4000 eggs, in 1-100 Hg $Cl_2$ for a few minutes.
4. Placed the fourth lot, of 3000 eggs, in a 20% solution of Cu $SO_4$ for a few minutes.
5. Placed the fifth lot, of 5000 eggs, in full strength lime-sulfur 31 to 32° B. for a few minutes.
6. Placed the sixth lot, of 3000 eggs, in 1-100 $H_2SO_4$ for a few minutes.
7. Placed the seventh lot, of 3000 eggs, in 1-50 $H_2SO_4$ for a few minutes.
8. Placed the eighth lot, of 3000 eggs, in 1-25 $H_2SO_4$ for a few minutes.
9. Placed the ninth lot, of 3000 eggs, in full strength $H_2SO_4$ for a few minutes.
10. Placed the tenth lot, of 2000 eggs, in 1-100 solution of 40% formaldehyde for a few minutes.
11. Placed the eleventh lot, of 3000 eggs, in 1-25 solution of 40% formaldehyde for a few minutes.
12. Placed the twelfth lot, of 3000 eggs, in 1-10 solution of 400% formaldehyde for a few minutes.

The results of this experiment are given in Table XII.

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TABLE XII.—ACTIVE LARVAE OBSERVED.

| Treatment March 21, 1914. | No. of eggs used. | March 22. | March 23. | March 24. | March 25. | March 26. | March 27. |
|---|---|---|---|---|---|---|---|
| 1. Liq. carbon bisulphide | 3000 | None | None | None | One | One | Abundant |
| 2. Vapor carbon bisulphide | 5000 | None | None | None | None | None | None |
| 3. $HgCl_2$ 1-100 | 4000 | None | None | None | Two | Many | Many |
| 4. $CuSO_4$ 20% solution | 3000 | None | None | Abundant | Abundant | Many | Many |
| 5. Lime-sulf. full strength | 5000 | None | None | None | None | Abundant | Many |
| 6. $H_2SO_4$ 1-100 | 3000 | Abundant | Abundant | Used for cu | lturing experi | ment. | |
| 7. $H_2SO_4$ 1-50 | 3000 | Very many | Very many | Used for cu | lturing experi | ment. | |
| 8. $H_2SO_4$ 1-25 | 3000 | None | None | None | None | Abundant | Abundant |
| 9. $H_2SO_4$ full strength | 3000 | None | None | None | None | None | None |
| 10. Formaldehyde 1-100 | 2000 | None | Abundant | Very many | Very many | Very many | Very many |
| 11. Formaldehyde 1-25 | 3000 | None | One | Two | Abundant | Very many | Very many |
| 12. Formaldehyde 1-10 | 3000 | None | None | Abundant | Abundant | Many | Many |

With the exception of the carbon bisulphide vapor treatment for six and one-quarter hours, and the full strength sulphuric acid treatment, it will be observed that the results of the various treatments of this experiment correspond with those of the previous experiments, where tubes of agar were used. As there was no more inhibition of hatching in this last experiment, where plain agar was used, than in the other tests, where synthetic agar was employed, it would seem that the various salts of the synthetic agar did not reduce the inhibitory powers of the chemicals used in the treatments.

EXPERIMENT XIII.

It was thought advisable to repeat the carbon bisulphide treatments to get more definite data than the previous experiments had supplied. March 23, 1914, dissected a number of egg masses from knots on lettuce roots, and divided them into three lots. After treatment, each lot was transferred to a tube of synthetic agar while still wet.

1. Placed the first lot in pure liquid carbon bisulphide for a few minutes.
2. Placed the second lot in carbon bisulphide vapor for one hour.
3. Exposed the third lot to strong carbon bisulphide vapor for sixteen and one-half hours.

The results of this experiment are given in Table XIII.

TABLE XIII.—ACTIVE LARVAE OBSERVED.

| Treatment March 23, 1914. | No. of eggs used. | Mar. 24. | Mar. 25. | Mar. 26. | Mar. 27. | Mar. 31. | April 3. |
|---|---|---|---|---|---|---|---|
| 1. Liquid Carbon Bisulphide | 5000 | Many | Many | Many | Many | Discontinued | Discontinued |
| 2. Carbon Bisulphide vapor | 6000 | One | Abund. | Abund. | Abund. | Many | Many |
| 3. Carbon Bisulphide vapor 16½ hours | 6000 | None | None | None | None | None | None |

In the case of the liquid treatment and the vapor treatment for one hour, it will be observed that abundant larvæ subsequently hatched from the eggs, while none hatched from the eggs exposed to the carbon bisulphide vapor for sixteen and one-half hours. From this it would ap-

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pear that the longer exposure to the carbon bisulphide vapor was the only cause of this difference. It was observed, however, that the egg masses dipped in liquid carbon bisulphide, and those exposed to the vapor for one hour did not become dried out as did those exposed to the vapor for sixteen and one-half hours. This observation caused us to raise the question as to what effect the loss of water might have on the results.

EXPERIMENT XIV.

March 24, 1914, dissected out a quantity of egg masses from knots on lettuce roots and placed them in a culture slide. The slide was then placed on the window sill at room temperature and left there until the next day. March 25, 1914, after eighteen and one-half hours of such exposure, the egg masses which had dried down to small, hard lumps, were transferred to a tube of synthetic agar. The results of this experiment are given in Table XIV.

TABLE XIV.—ACTIVE LARVAE OBSERVED.

| Treatment March 24-25, 1914. | No. of eggs used. | March 26. | March 27. | March 28. | March 31. | April 3. |
|---|---|---|---|---|---|---|
| Dried at room temp. for 18½ hours..... | 10,000 | None | None | None | None | None |

As the egg masses had no surface disinfection, they were not free from viable fungus spores, so by March 31, 1914, the surface of the medium was so over-run by fungi that the egg masses could no longer be distinctly seen. The result of this experiment is the same as that of the long exposure to carbon bisulphide vapor; so it would appear that the drying which the egg masses underwent in the vapor treatment, might have had some inhibitory effect.

In looking over the data on some of the earlier experiments, it was observed that in many cases the writer had subjected the egg masses to the chemicals for longer periods of time than in the later experiments. It was thought that this longer exposure, ten to thirty minutes, might have caused the difference in results. To test this point it was decided to run a series of treatments in which the egg masses should be exposed for thirty minutes or more to the chemical used, before being transferred to the tubes of agar.

EXPERIMENT XV.

March 30, 1914, a large number of egg masses were dissected from knots on squash and tomato roots and divided into seven lots. After treatment, each lot was transferred to a tube of synthetic agar.

1. Placed the first lot, of 5000 eggs, in 31-32° B. lime-sulfur for thirty minutes.
2. Placed the second lot, of 5000 eggs, in full strength "Black Leaf 40" for thirty minutes.
3. Placed the third lot, of 3000 eggs, in 1-100 solution of 40% formaldehyde for forty-five minutes.

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4. Placed the fourth lot, of 5000 eggs, in 1-25 solution of 40% formaldehyde for forty-five minutes.
5. Placed the fifth lot, of 5000 eggs, in 1-10 solution of 40% formaldehyde for thirty minutes.
6. Placed the sixth lot, of 5000 eggs, in 20% $CuSO_4$ for thirty minutes.
7. Placed the seventh lot, of 5000 eggs, in 1-50 $H_2SO_4$ for thirty minutes.

The results of this experiment are given in Table XV.

TABLE XV.—ACTIVE LARVAE OBSERVED.

| Treatments March 30. 1914. | No. of eggs used. | Mar. 31. | April 1. | April 2. | April 3. | April 4. | April 5. | April 6. | April 7. |
|---|---|---|---|---|---|---|---|---|---|
| 1. Lime-sulfr. 31-32° B. | 5000 | None | None | One | None | None | Ten | Abundant | Abundant |
| 2. "Black Lf. 40" full strength..... | 5000 | None | None | None | None | None | Two | None active | None active |
| 3. Formaldehyde 1-100. | 3000 | None | One | Abund. | Abund. | Abund. | Abund. | Abundant | Abundant |
| 4. Formaldehyde 1-25.. | 5000 | None | None | None | Abund. | Abund. | Abund. | Abundant | Abundant |
| 5. Formaldehyde 1-10.. | 5000 | None | None | None | None | None | 12 | Abundant | Abundant |
| 6. $CuSO_4$ 20%..... | 5000 | None | None | None | 7 | Abund. | Abund. | Abundant | Abundant |
| 7. $H_2SO_4$ 1-50..... | 5000 | 5 | Abund. | Abund. | Abund. | Abund. | Abund. | Abundant | Discontinued |

In the case of the lime-sulfur and the "Black Leaf 40" treatments, the smaller number of active larvœ recorded was due to the fact that the medium was so clouded by the treatments that larvæ could not be distinguished unless they crawled up on the sides of the tubes above the substratum. From the result of this experiment, it would seem that the longer exposure to the chemicals does not affect the ability of the eggs to hatch.

In attempting to subject the eggs to the same conditions that they are under in the actual soil treatments, it would appear that they should be exposed to the chemical for only a short time. In soil treatments we cannot conceive of the eggs being subjected to the chemical except just during the period when the solution is passing down through the soil directly after being applied at the surface. The various vapor treatments are exceptions to the above statement because they exert an influence throughout the time they are present in the soil.

## SUMMARY OF THE LABORATORY EXPERIMENTS.

Although the number of experiments conducted so far is not great, the number of eggs used in each experiment was so large that we feel justified in drawing certain conclusions from the results. The results of the earlier experiments were somewhat erratic; but taken as a whole, this series leads one to conclude that the chemicals used cannot be depended upon to control the root-knot nematode, because they do not completely inhibit the hatching of the eggs. We do not feel justified in concluding that this is the only reason for the failure of the chemical treatments in the field experiments, because we have not as yet collected sufficient data on the other theories to draw any definite conclusions regarding them. Stone and Smith (6) found that chemicals failed to inhibit the

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development of the eggs of certain free-living nematodes. The results of the above-mentioned workers, together with those obtained by the writer with the eggs of the parasitic nematode, *Heterodera radicicola*, indicate that further work along this line may establish the fact that the other parasitic nematodes will be able to survive soil treatments with chemicals for the same reason, namely, that the egg stage in the life cycle is resistant to the chemicals.

### DATA ON STEAM STERILIZATION OF SOIL.

During the summer of 1913 it had been intended to conduct experiments on the control of the root-knot nematode by steam sterilization, but it was impossible to get a steam boiler for a sufficient length of time to prepare complete experiments. The writer did succeed in getting a boiler for one day, and so was able to collect some data relative to the depth to which the soil could be heated in a given length of time with equipment such as he had. The method and results of this work as given below, will give an idea of the value of steam, but these results are not sufficient to serve as a basis for definite recommendations. A pan ten feet six inches long, three feet wide, and six inches deep, was used in this work. Steam was furnished by a ten horsepower boiler kept at a pressure of seventy pounds. The soil to be treated was first thoroughly spaded up to loosen it to facilitate the penetration of the steam.

In order to get data on the depth to which the steam penetrated, potatoes were placed in the soil at three places, viz., at the end of the pan where the steam entered, at the opposite end, and at the middle. Holes eighteen inches deep were dug and stakes set in them to mark the location of the potatoes. One potato was placed at the bottom of each hole, eighteen inches below the surface, and the soil was shoveled in until the holes were twelve inches deep. At this depth potatoes were placed in each hole and soil shoveled in until the holes were six inches deep. Potatoes were placed in each hole at this depth, and then the holes were filled until they were but three inches deep. Potatoes were placed at this depth and the holes were then filled up until the soil was level over the whole plot. The pan was then connected up with the boiler and the steam turned on. In about fifteen minutes the steam began to lift the pan out of the soil so that steam escaped from under its edges. To avoid this loss of steam, the pan was weighted down with scrap iron. After thirty minutes of treatment the steam was shut off and the pan removed from the soil. The potatoes in the hole farthest from where the steam entered the pan, were dug first. The potatoes at three inches, six inches, and twelve inches below the surface were well cooked throughout and the one at eighteen inches below the surface was very hot. Next, the potatoes in the middle of the plot were dug up, and all found to be well cooked, even the one eighteen inches below the surface. It was next attempted to dig the potatoes at the end of the plot where the steam entered, but the steam had gouged out such a hole in the soil that it was impossible to locate all of them. The two that were found were well cooked. The soil treated is a very fertile clay loam, with a stiff clay subsoil at about twenty-four inches below the surface.

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This steam experiment was next repeated on an adjoining plot of soil exactly as before, except that the steam at eighty pounds pressure was run into the pan for fifteen minutes instead of thirty minutes. At the end of the period the pan was removed and the potatoes were dug. The potato at three inches below the surface was thoroughly cooked. Potatoes at six and twelve inches below the surface were partly cooked. The potato at eighteen inches below the surface was very hot. Of these two treatments, the thirty minute steaming was the better, as judged by the condition of the potatoes. Where the potatoes were well cooked, it is quite reasonable to suppose that the nematodes were killed, but the writer is not certain of this point.*

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The writer is indebted to Dr. E. A. Bessey, Botanist, Michigan Agricultural Experiment Station, for many suggestions and much helpful advice.

To Dr. L. R. Jones, Plant Pathologist, Wisconsin Agricultural Experiment Station, the writer is indebted for much helpful criticism.

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*NOTE: Observations made by E. A. Bessey in the summer of 1915 on these and similarly treated adjacent lots of formerly badly infected soil show the total absence of root-knot nematodes both one and two years after the steam treatment.

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MICHIGAN AGRICULTURAL COLLEGE

EXPERIMENT STATION

DIVISION OF ENTOMOLOGY

# HOW CONTACT INSECTICIDES KILL.

## III. RELATING EVIDENCE, FURTHER, OF CERTAIN PROPERTIES OF CARBON DISULPHIDE, GASOLINE, AND A FEW OTHER FLUIDS, AS WELL AS TEMPERATURE AND SOME DRY POWDERED CONTACT INSECTICIDES, BY MEANS OF WHICH THE INSECTICIDAL ACTION OF THESE AGENTS IS ACCOMPLISHED AFTER THEIR ABSORPTION INTO THE INSECT TISSUES, OR AFTER MERE APPLICATION—INCLUDING ALSO BRIEF SUGGESTIONS FOR POSSIBLE PRACTICE.

BY

GEORGE D. SHAFER

EAST LANSING, MICHIGAN
1915

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# HOW CONTACT INSECTICIDES KILL.

III. Relating evidence, further, of certain properties of carbon disulphide, gasoline, and a few other fluids, as well as temperature and some dry powdered contact insecticides, by means of which the insecticidal action of these agents is accomplished after their absorption into the insect tissues, or after mere application;—also brief suggestions for possible practice, by George D. Shafer.

## INTRODUCTORY STATEMENTS.

### (a) FORMER EVIDENCE.

In a former paper on the subject, "How Contact Insecticides Kill*," it has been shown that many gaseous or volatile contact insecticides mainly become effective after being taken up by the insect tissues. Certain color tests and actual volume measurements demonstrated that gaseous insecticides, (such as $H_2S$, HCN and $NH_4$) and the vapor of carbon disulphide, as well as that from many volatile oils (e. g. kerosene, gasoline, benzine, turpentine) are absorbed by the tissues of insects. Much evidence was pointed out which indicated that vapors of gasoline, carbon disulphide and the like, after absorption, accomplish their effect upon insects through some tendency their presence exerts to prevent oxygen assimilation in the tissues.

If the vapors of the insecticides mentioned do interfere with oxygen assimilation, upon what do they act in the tissues to bring about that condition?

At the time the former bulletin was written nothing had been done upon this latter phase of the problem. It is with facts that seem to relate to this phase of the question that the present bulletin has to do. Careful examination was made of the organs of treated insects and many histological studies were made. When an insecticide, such as gasoline, was present in abundance, it was found that after several hours the fatty tissues went more or less into solution. Insects were crushed and an attempt was made to detect changes which carbon disulphide, kerosene, gasoline and the like might have upon the tissue-pulp. It was easy here also to notice the solvent action of gasoline, kerosene and carbon disulphide upon the fats and fat-like substances in the pulp. The action of carbon disulphide upon protein in the pulp could also be seen. The concentrated vapor of carbon disulphide would, in time, coagulate and whiten certain proteins. Egg-albumen readily shows this action of carbon disulphide vapor, after a few hours confinement with air *saturated* at about 68° to 70° F. with that vapor. Studied in this way, however, using only such amounts of the agents in question as were necessary to *kill* insects, there was no visible effect on the tissue pulp which might be held as a sufficient cause for rapid death.

*Parts I and II, Tech. Bulletin No. 11, Mich. Agr. College Exp. Station.

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As already pointed out, however, a rise in the respiratory ratio during the time insects were dying, afforded the strongest evidence of an inhibition of oxygen assimilation. It was decided, therefore, to determine the respiratory exchange of fresh insect tissue pulp and to see whether this exchange became influenced by gasoline, for example, in the same manner as had already been found for insects themselves. That the pulp does have a decided respiratory exchange, and that this is influenced by gasoline vapor in the same manner as the latter influences the respiration of insects may be seen by comparing table I-A with table V of part I, Tech. Bull. No. 11.

TABLE I.

A.

| Extract pulp of tissues of *Passalus cornutus.* | Treatment. | Temperature. | Respiratory period. | $\frac{CO_2}{O_2}$ |
|---|---|---|---|---|
| 5 c. c. | Gasoline | 24.2° C. | 16 hrs. | $\frac{2.1}{1.2} = 1.7$ |
| 5 c. c. same sample | None | Same. | Same. | $\frac{2.8}{3.4} = 0.82$ |
| 5 c. c. | Gasoline | 24.2° C. | 7½ hrs. | $\frac{0.9}{0.4} = 2.2$ |
| 5 c. c. same sample | None | Same. | Same. | $\frac{0.5}{1.0} = 0.5$ |
| 5 c. c. | Gasoline | 25.4° C. | 16½ hrs. | $\frac{3.1}{1.3} = 2.3$ |
| 5 c. c. same sample | None | Same. | Same. | $\frac{4}{5} = 0.8$ |

B.

| Extract pulp of tissues of *Passalus cornutus.* | Treatment. | Temperature. | Respiratory period. | $\frac{CO_2}{O_2}$ |
|---|---|---|---|---|
| 5 beetles (uninjured) | None | 20.8° C. | 1 hr. | $\frac{3.2}{4.49} = 0.71$ |
| Same 5 beetles | Opened and digestive tracts removed. | 21° C. | 1 hr. | $\frac{0.89}{0.8} = 1.1$ |
| 5 beetles | " " | 20.4° C. | 18 hrs. | $\frac{6.4}{7.9} = 0.81$ |
| 5 beetles | " " | 20.8° C. | 6 hrs. | $\frac{2.7}{2.9} = 0.9$ |

Gasoline was selected for making this test because of all the volatile insecticides employed, it permitted of the most accurate volumetric determinations of its own vapor, and of the oxygen, carbon dioxide and nitrogen present at the beginning and at the end of the test. The apparatus and the method employed for making the gas determinations has been described in Part I of the former bulletin. The insect-tissue pulp was contained in a small, sterile, open glass stender dish which floated on the mercury in the respiration container. The pulp, or crude tissue-

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extract, was prepared as follows: The insects were thoroughly cleaned with absolute alcohol and a cloth. In the case of *Passalus cornutus*, which was mostly used, the wing-covers and wings were first removed. Then the digestive tracts were carefully removed entire, and discarded. The remainder of the tissues—blood, fat, muscles, nervous tissue, etc.—became thoroughly "ground up" in a mortar with a little distilled water.

It will be noticed that the respiratory ratio of the pulp or water extract of insect tissues proved to be rather higher, often, than was the case for healthy, uninjured beetles. A few respiration experiments were run, using insect bodies from which the digestive tracts had been removed. The ratio of carbon dioxide given off to oxygen taken up was in this case, also, a little higher usually than the ratio for normal healthy beetles. (See B, table I). Mechanical injury, through crushing without external mutilation, or through pithing the beetles with a hot needle, however, gave a ratio for the respiratory exchange lower than that of healthy normal beetles. But as has already been pointed out, when air saturated with gasoline vapor was used either with the insects themselves, with the tissue-pulp or with the crude water extract, it regularly caused a decided rise in the respiratory ratio above that given by the same insects, tissue pulp, or crude extract. Thus it began to appear as if whatever bodies were present in the living insect tissues to start and carry forward the respiratory process—these were able to maintain themselves as "respiratory bodies" (with limited activity) for a time, at least, in the insect tissue pulp and in the crude extract of the pulp, where the effects of the insecticides in question might still be studied.

### (b) OXIDASES, CATALASES AND REDUCTASES IN ANIMALS AND PLANTS.

In the pulp and in the water extract of various tissues of many vertebrate and other animals and in many plant tissues, workers have described enzymes which are able not only to carry forward oxidation processes in the pulp or extract itself, but also to initiate or accelerate the oxidation of certain other bodies, such as gum guaiac, hydroquinone, tyrosine, etc., when these are added in solution to the extract. Such enzymes have received the general name of oxidases. It is not the purpose here to give a discussion of oxidasic enzymes, their kinds and possible functions in the living tissues in connection with other enzymes or enzyme-like bodies; but a short statement will make clear the import of the experiments which follow in this connection. None of the oxidases have been obtained in a known pure and isolated form, yet much has been learned of their properties, and of their more or less specific action, so that they have generally received names according to the kind of body or bodies upon which they have been found to act—as alcoholases, aldehydases, phenolases, or laccase, tyrosinase, etc. Associated generally, if not always in pulp or tissue-extract with oxidases, various workers have found peroxidases, catalases, and reductase (or reductases). The peroxidases of tissue extracts (when they clearly show themselves present) are substances which activate peroxides—for example they cause hydrogen peroxide to change in such a way that its oxygen may became transferred to guaiac, causing oxidation of the latter to guaiac blue. Peroxidases serve as activators merely; they do not cause the liberation of free oxygen from the peroxides. Indeed an oxidase is now looked upon

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by most workers in this field as an organic peroxide, or an oxygenase (i. e. a substance capable of quickly forming an organic peroxide by uniting with oxygen from air) working with a peroxidase. The alpha and beta catalases, as demonstrated by Loew, are enzymes which are capable of breaking down $H_2O_2$ into molecular oxygen and water, the oxygen coming off in bubbles. Finally, tissue pulp from plants and from animals has been found to possess a more or less strong reducing power. This power has been generally attributed to reducing enzymes called reductases. Knowledge of the functions and properties of the enzymes mentioned above is, as yet, very incomplete. Satisfactory proof has not been obtained in some cases, and there are those who believe that reductases and catalases are not enzymes at all. As experiments and observations accumulate, however, there seems to be a growing number, among those actively engaged in investigation of the subject, who believe that in the oxidases, catalases, and reductases we have to do with a part, at least, of the machinery which accomplishes oxidations and respiration in the protoplasm of living cells. Alexis Bach, for example, has gone so far (in 1913)*, in a discussion of oxidising and reducing enzymes, as to express his belief in their role in the process of respiration rather definitely. E. F. Armstrong in the "Journ. of the Chem. Soc. 104, Part I, p. 543, abstracts Bach's conclusions as follows:

"(1) In order to utilize the oxygen of the air to effect oxidation, the cell produces an enzyme (an oxygenase)—a substance which is readily oxidized, fixing molecular oxygen to form a peroxide. (2) A second enzyme (the peroxydase) accelerates the oxidizing action of the peroxides, acting on them in the same way as ferrous sulphate does toward $H_2O_2$. (3) The peroxides are readily transformed by hydrolysis into $H_2O_2$ which is also formed as a primary product during hydrolytic oxidation. Owing to its rapid rate of diffusion, this accumulation of $H_2O_2$ might damage the cell protoplasm. To guard against this, the cell produces an enzyme—catalase, which rapidly decomposes $H_2O_2$ into water and inert $O_2$. Catalase thus acts as a regulator of the respiratory process. (4) To effect hydrolytic oxidation, an enzyme-perhydridase—is present which accelerates both oxidation and reduction just as do the metals of the platinum group. The reductase consists of the enzyme, water and an oxidisable substance which fixes the oxygen derived from the water, leaving the hydrogen free to effect reduction."

In view of the importance which physiologists begin to attach to oxidizing and reducing bodies in tissue extracts of animals and plants, and because of the influence which certain of the contact insecticides are now known to have upon the respiratory exchange of insects, it seemed worth while to investigate these bodies in insect tissue extract and to study the effect of gasoline, carbon disulphide, and some other contact insecticides upon the activity of those found to be present.

### (c) OXIDIZING AND REDUCING BODIES IN INSECT TISSUE PULP OR EXTRACT.

The method used in preparing insect tisue pulp for study has already been described. In preparing the crude extract the pulp was ground up with a small amount of sterile distilled water—usually about twelve to fifteen cubic centimeters to five or six adult specimens of *Passalus*

*(Arch. Sci. phys. nat., 1913, vol. 35, 240-262).

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*cornutus*. Then the extract was pressed out through Swiss muslin. The crude extract obtained in this way was whitish or creamy in appearance, at first, due to fat and very tiny particles of tissue which came through the muslin. When this extract was filtered through heavy filters under twenty to twenty-five pounds pressure, a clear or slightly straw-colored filtrate was obtained, and (on the filter) a considerable residue. When either the crude extract or the filtrate was allowed to stand for a time, the surface in contact with the air turned dark while the deeper parts of the fluid remained as at first for hours—for more than a day if kept cool or treated with a *little* of some weak antiseptic like chloroform, sodium fluoride solution, toluol or ether. Whenever work with the extract extended over several hours, some such antiseptic was used provided the nature of the experiment would permit. If to about 1 c. c. of the crude extract a few (2 to 5) drops of a saturated solution of alcoholic guaiac were added, the milky mixture would begin to show a tinge of blue within one or two minutes, and would gradually develop a beautiful deep blue coloration. When about 1 c. c. of a standard hydroquinone solution* was added to 3 c. c. of the extract, it slowly began to turn reddish brown; and after several hours, the entire mixture appeared very dark brown or perhaps almost black, giving off a decided odor of quinone. Vernon's alpha-naphthol paraphenylene-diamine mixture† was tried, and this, the crude extract rapidly oxidized to the blue indophenol. Finally, the extract was able to slowly oxidize tyrosine (Merck) until after a few hours one obtained a heavy black or melanic pigment. It was interesting to drop a small pinch of tyrosine crystals into a little extract from *P. cornutus* tissue, and then watch the black coloration develop about it. The extract clearly possessed oxidasic properties. Moreover, the filtrate and the washed residue left from filtering the crude extract under pressure gave the reactions showing the presence of oxidases. That is, oxidases soluble in water and insoluble in water were present. Likewise two catalases, one soluble in water and going with the filtrate, the other insoluble in water and remaining in the washed residue, were found to be present as first described by Loew‡ in the tobacco plant, and both were very active in liberating bubbles of oxygen from hydrogen peroxide.

Some of the fresh extract which had just darkened was confined in the absence of oxygen, and it became rapidly changed back to the appearance it had before it had darkened. If a few drops of a methylene blue solution were added to some of the extract and then the latter were confined from the oxygen of the air, the blue color became entirely reduced. Reducing bodies, therefore, seemed to be present; and besides, the reduction of methylene blue took place whether it was confined with the filtrate of the crude extract or with the washed residue. Thus, oxidases, catalases, and reducing bodies were all found to exist in the pulp and in the crude water extract of *P. cornutus* in two forms, one being soluble and the other insoluble in water. It therefore seemed desirable to make

*This standard solution was made up by dissolving 1.1 grams of hydroquinone in 100 c. c. of distilled water.

(I. e. $\frac{m}{10}$ hydroquinone.)

†Vernon, H. M. The Quantitative estimation of Indophenol Oxidase of Animal Tissues. The Journal of Physiology, Vol. XLII., Nos. 5 and 6, pp. 402-427.

‡Oscar Loew: Report No. 68 Div. of Veg. Phys. and Path., U. S. Dept. of Agr., 1901.

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a further study of these oxydasic and reducing bodies of *P. cornutus* and to determine the effect of some of the contact insecticides upon their activity. How, for example, would gasoline vapor or the vapor of carbon disulphide affect the rate at which the crude water extract could oxidize a solution of hydroquinone? When present in concentrated amounts, the rate at which oxygen was absorbed by insects and by crude insect tissue-extract was lowered by these insecticides. Would they reduce the rate at which the oxydases in the extract caused guaiac or hydroquinone to become oxidized?

## THE EFFECT OF GASOLINE AND SOME OTHER CONTACT INSECTICIDES UPON THE OXIDASE, CATALASE, AND REDUCTASE ACTIVITY IN EXTRACTS OF THE TISSUES OF *P. CORNUTUS*.

### (a) EFFECT UPON OXIDASIC ACTIVITY.

It has been pointed out that both soluble and insoluble oxidases were found to be present in the extract of *P. cornutus*. The insoluble oxidase (oxydone*) remained in the mixed residue on the pressure filter after filtering the crude extract, while the soluble form went through in the clear or straw-colored filtrate. When the latter was treated with alcohol or saturated with ammonium sulphate until the proteins were thrown down, the oxidase separated with them and could be filtered out. The oxidasic activity of this alcoholic or ammonium sulphate precipitate could be preserved for hours or even days, if the precipitate were kept moist and cool; but drying, even at room temperature, almost if not entirely destroyed the activity of the oxidase in a few hours. On the other hand, when the washed residue containing the oxydone was moistened after having been dried at room temperature for 36 hours or even longer, it exhibited oxidasic action toward alcoholic guaiac almost undiminished. Moreover, in the dry condition, the oxydone was very resistant to heat. It could then be kept at 90° to 100° C. for an hour without destroying all of its activity. When moist, as in the crude extract, however, both the oxidase and the oxydone were destroyed if kept at a boiling heat for 10 minutes; and nearly all oxydasic activity was destroyed if a crude extract were kept at 80° to 81° C. for 15 minutes. When kept at 68° to 69° C. for one hour, such an extract was 5 to 6 times longer in oxidizing alcoholic guaiac than a check kept at room temperature for the same time. In making this comparative test with alcoholic guaiac, the same amount of extract was used for the check as for the heated portion, and at the end of the test period a certain number of drops of the guaiac solution were added to each portion. Then the time required to oxidize the guaiac in the treated and untreated extracts to the same depth of blue coloration was noted. This was a method by which only well marked differences might be compared, but by its use one could easily see also that solutions of hydrochloric acid, borax, sodium fluoride, nicotine (to-bak-ine) and ammonia all exerted a more or less harmful

*Insoluble oxydases in animal tissues are referred to as "oxydones" by Batelli, and (Mlle) Lina Stern, Biochem. Zeitsch. 1913, *52*, p. 226. Rev. in J. of Chem. Soc. vols. 103-104 pt. i, p. 929.
The work of these investigators did not come to the notice of the author until early in 1914, when this phase of his own work was nearly finished—having been begun in 1912.

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influence upon the ability of the crude extract to oxidize guaiac (exposed to the air) when they were added in small amounts. Both the oxidase and the oxydone were affected. The influence of carbon disulphide, gasoline, and hydrocyanic acid gas were studied in the same manner. In the case of carbon disulphide and gasoline, the influence of both the vapor and the liquid of each fluid was studied—using the vapors to saturation in air, and the liquids at the rate of three drops to 2 c. c. of extract thoroughly mixed to an emulsion.

Carbon disulphide deterred the oxidation of guaiac by the extract greatly;—sometimes the blue coloration did not begin to develop until after two hours, when the extract had been treated with the concentrated vapor or with the liquid for a few hours before testing. The influence of carbon disulphide was most marked when the extract was rich in fat-emulsion.

The influence of concentrated gasoline vapor on the oxidasic properties of an extract, as studied by the aid of alcoholic guaiac, was never very decided. However, the liquid gasoline first used appeared quite destructive to the oxidase, but that sample of gasoline was later found to be slightly acid in reaction; and when this acidity was rendered just neutral, the liquid gasoline then acted scarcely more harmfully than the concentrated vapor. In fact if either the vapor or the liquid gasoline were used with perfectly fresh milky extract (rich in fat) it seemed to hasten the bluing of guaiac—or to hasten the darkening of the extract itself on standing alone in air.

In the case of hydrocyanic acid gas, it was found that if an extract were tested immediately after being removed from the treatment, the guaiac blued very much more slowly than in the check. If, however, the treated extract were allowed to stand in air for an hour or so until it became free from the odor of hydrocyanic acid, the guaiac blued almost as rapidly upon being added as in the check extract.

Borax (3 grams in 100 c. c. distilled water) was very destructive to both the oxidase and the oxydone, when a little of the solution was shaken up with the extract and allowed to stand for a few minutes.

Sodium fluoride, in saturated solution, was used. It retarded the development of guaiac-blue when added in considerable amounts to an extract, but even 1 c. c. of the solution mixed with 1 c. c. of the extract did not prevent the development of the blue coloration after an hour or two. When added in only small amounts to a fresh extract, sodium fluoride solution seemed to hasten the bluing of guaiac. Likewise chloroform and ether did not seem to injure the oxidasic activity of the tissue extract toward alcoholic guaiac, except very slightly when they were used in large amounts and thoroughly shaken up with the extract.

This study with alcoholic guaiac was instructive, but a method was sought which would show by *volume measurements* of the oxygen taken up just what influence carbon disulphide and gasoline (for example) had upon the rate at which oxygen was absorbed by insect-tissue-extract plus some other substrate than guaiac. Hydroquinone solution was selected as the substrate to be oxidized because it was easy to keep a comparatively constant, clear, standard solution for some time, and because as the oxidation to quinone proceeded, the color of the solution changed progressively from a reddish to a darker and darker coloration. Thus, a color check was afforded, upon the volume of oxygen used in the case

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of treated (with insecticide) and untreated extract samples. (See Fig. 1, Plate I.) So many factors were involved that it was necessary to use extreme precaution in order to be at all sure that a difference in volume of the oxygen absorbed by hydroquinone-extract-mixture in air and hydroquinone-extract in gasoline-vapor-air was due alone to the influence of gasoline vapor. It was necessary always to thoroughly mix a fairly concentrated extract and then to remove two equally measured samples for the experiment at as nearly as possible the same time. Furthermore, exactly equal measures of a standard hydroquinone solution must be added to the two samples at the same time, and then the tests with the two equally prepared mixtures must necessarily be run (the one in air and the other in gasoline-air) under like conditions of temperature for the same period of time. It would not do to run the tests for equal periods, merely. They must cover the same period as nearly as that might be made possible. The reason for these precautions, if not apparent here, will be noticed later in the discussion. Another difficulty presented itself. Oxygen was absorbed rather slowly in the tests, and so it seemed advisable to find some method of measuring directly the entire amount of carbon dioxide that might be given off, as well as the entire amount of oxygen taken up, rather than to depend upon percentage estimations from samples. No method was available for removing and accurately estimating carbon disulphide vapor from air used in a test, and so it seemed necessary to be able to measure the oxygen taken up and the carbon dioxide given off *in the presence* of the insecticide employed during the test. Finally, an apparatus was devised which complied very well with the requirements just outlined. The essential features of the apparatus are represented in Figure 1, and a brief description follows here.

The apparatus (Fig. 1), consisted of two systems which were almost exact duplicates, each made up of a gas-burette "a" connected with a mercury-mug "b"; a gas-container "c"; a potash absorption flask "d"; a mercury manometer "e"; a burette "f" (graduated to O. 1 c. c.) for the hydroquinone solution; and a circulating pump "g". The gas container was of about 300 c. c. capacity, with two two-way cocks above and a wide mouth (2½ inches) beneath. The wide rubber-stopper for this container was connected with a mercury-mug "h", and a hooked U-tube also passed from the stopper to connect with the hydroquinone burette "f". Mercury could thus be used not only to seal the mouth of the gas-container, but to float the stender dish up under the hooked end of the U-tube. The gas-burette of each system was connected by tubes (with airtight sealed joints) through the corresponding gas-container, absorption-flask, mercury manometer and circulating pump of its system, as represented in the figure. Between the "pump-gas-container connecting tube" and the "absorption-flask-pump connecting tube" was a cross tube with a stopcock "St." Fig. 1. This cock was kept closed when the pumps were running. It was opened as soon as the pumps were stopped, and always, before the manometers were adjusted, the circulating wheel of each pump was given a quarter turn backward. Thus, any air that might be compressed in a pocket was released into the upper air-chamber, leaving the pockets filled with mercury. The circulating pump of each system was actuated by belts from the same double pulley of a reducing

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gear "j", which was run by a small motor not shown in the figure. It was thus possible to start and stop the pumps (which were duplicates) at the same time and to run them at the same speed. There was not found, on the market, a small pump in which the gas to be circulated did not come in contact with the boxing of the pulley-journal of the

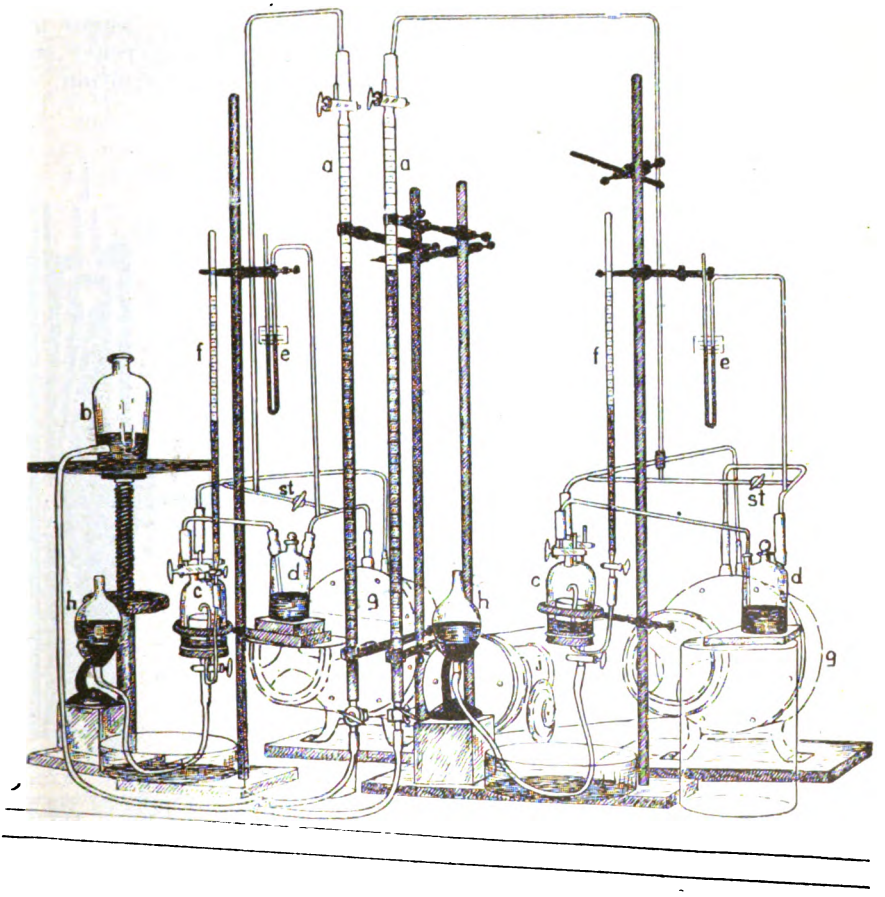


**Fig. 1.** Apparatus used in determining the influence of gasoline and carbon disulphide upon the absorption activity for oxygen of insect tissue-extract plus hydroquinone solution. (Duplicate systems) a = gas burettes; b = mercury mugs; c = gas-containers; d = potash absorption flasks; e = mercury manometers; f = burettes for hydroquinone solution; g = circulating pumps; h = mercury mugs; j = reducing gear.

pump. In these experiments, it was necessary to *know* that no leak or gas exchange could take place at that point. The two circulating pumps represented in Fig. 1 were, therefore, designed to meet the necessity. Each pump was filled with mercury to a certain level as shown by line

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"a-c", Fig. II. The circulating wheel "w" pointed out in the same figure was made to revolve in the mercury in the direction of the large arrow. Each pocket in the wheel thus carried gas from the air-chamber in the upper part of the pump down into the mercury to the position "p", when the air emptied toward the center (due to its tendency to rise in the mercury) and came out into the outlet tube "o" as shown in Fig. II B. The pump was therefore able to circulate air against a pressure equal to the mercury-height "s-t", and the confined gas in the pump could not come in contact with the pulley journal "j" under any circumstances, since the lowest level "s", to which the mercury could be brought, was higher than the pulley-journal. As a precaution, a small

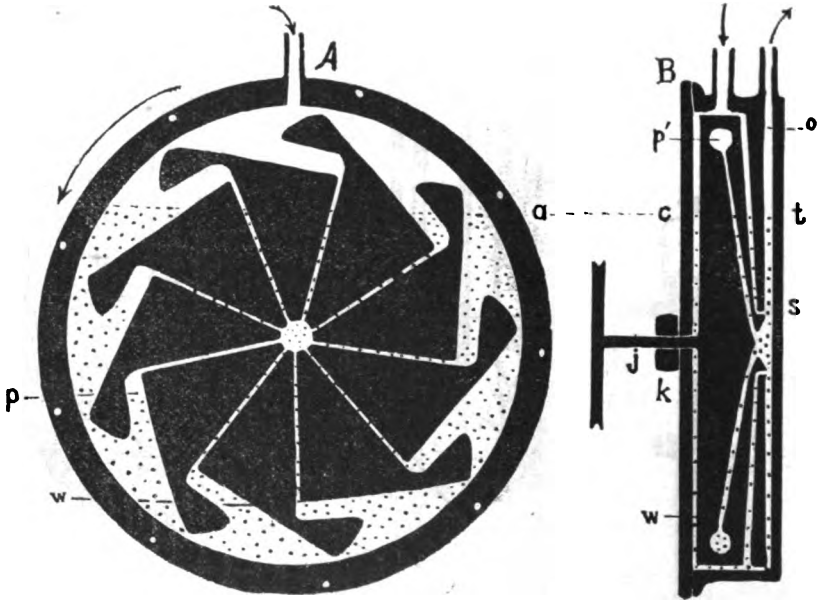


Fig. II. Diagrammatic projections of the working parts in gas-circulating-pump (see "g" Fig. 1). A = Side-projection; B = Edge-projection; a-c = level of mercury; w= circulating wheel; p = position of air pocket when it empties toward the center; p' = air pocket; o= outlet tube; s = bearing around the common central outlet for the air pockets in the circulating wheel; j = pulley journal.

cup was set beside each pump (when in use) just beneath the boxing "k". If a mercury leak should have occurred from this point, the volume of the leak could have been known at once from the mercury caught in the cup. When the apparatus was set up, much trouble was experienced in getting all connections sealed gas-tight. Tests were not begun with the extract, however, until the apparatus was able to stand, for several hours, under a pressure greater than any that might occur in the regular experiments, without showing a measurable leak. Moreover, test experiments were run with samples of the same extract in air in both gas-containers of the apparatus until comparatively uniform results

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were given. The working difference which might occur between the two systems of the apparatus was about 0.2 c. c. When a test to obtain the influence of gasoline-vapor or carbon disulphide vapor upon the hydroquinone-oxidase activity of insect tissue extract was to be run, equal samples from the same tissue-extract were placed in each of two sterile stender dishes of 36 m. m. diameter, and the dishes were introduced into the two gas-containers "c." "c.", Fig. I. Mercury seal was made at the mouth of each gas-container, and the U-tubes were connected with the hydroquinone burettes. Then, by means of the mercury-mug and the free opening of one of the two-way cocks of one gas-container, as much insecticide vapor as was wanted could be introduced from a separate stock-container of concentrated insecticide vapor. After that, the cocks of the gas-containers were opened to the outside an instant until both mercury manometers read level. The temperature was recorded. Then the cocks were all properly set and the motor started, so that in the two systems the gas or air was made to circulate until it was uniformly mixed. The motor was stopped and started in this way several times (pressure adjustments being made between times, if necessary) until the manometers stood level after each short interval. The cocks of the gas-containers were then quickly opened to the outside, and hydroquinone solution was carefully let down from the burettes until it reached the openings of the hooked U-tubes above the stender dishes in the two containers "c." "c." A measured amount, usually 2 c. c. of hydroquinone solution to 5 c. c. of the tissue extract, was measured into each extract stender dish. Test was again made to see that the pressure manometers stood level and then both cocks of each gas-container were closed. The temperature was again noted. The barometer reading and the readings of the two gas-burettes were recorded. The apparatus then stood during the desired period of the test in a room where the temperature varied but little—and only very slowly—and one could be sure that both systems of the apparatus were at the same temperature when readings of the gas-burettes were made. At the end of the test period, the cocks at the top of the gas-containers were turned so as to connect each container with its own system. The mercury in each gas-burette was quickly manipulated so as to bring the mercury manometers level, and the readings of the two gas-burettes were taken. Then the cocks "st" and "st'" were closed and the pumps were started. The gas or air in each system was thus made to circulate through the absorption flasks until trial showed that the readings of the gas-burettes (after short runs of the pumps) were constant, when the two manometers "e" and "e" stood at zero. The reading of each gas-burette was then again recorded. Thus there were three gas-volume readings for the system containing the insecticide-treated extract and three for the check. The first reading in each set showed the constant volume of the gas under certain recorded conditions of temperature and barometric pressure; the second showed the volume after oxygen absorption (i. e. by the extract containing hydroquinone solution), before any carbon dioxide had been removed; and the third reading gave the volume after the carbon dioxide produced during the experiment period had been circulated through the hydroxide flask and absorbed. The readings were all reduced to the

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volume which would be given at 0°C. and 760 m. m. mercury pressure so that they might be safely compared. The second reading, then, minus the third (in each set of reduced readings) showed the volume of carbon dioxide produced during the period; and since no carbon dioxide was present at the beginning, the first reading minus the third gave the volume of oxygen that had been absorbed during the test. The volume of oxygen absorbed in the case of the insecticide-treated "extract plus hydroquinone" and the volume of oxygen absorbed by the untreated "extract plus hydroquinone" could thus be compared directly; and it is believed that any difference must be attributed to the influence of the insecticide present, since other conditions were kept as nearly as possible the same.

Checks tried separately had shown that gasoline and carbon disulphide vapors were not appreciably affected by the potassium hydroxide solution used, and that they did not interfere with its absorption of carbon dioxide.

The records of a test are given here as they were kept for a regular experiment:

Exp. 7. Used 5 c. c. of an extract (made from 4 large "white grubs" in 20 c. c. distilled water, plus 3 drops of Toluol) in each of the two containers—right and left.

Ran pump at intervals until readings became constant. Added 2 c. c. or $\frac{N}{100}$ hydroquinone solution to each. Ran pumps short interval—readings were constant.

Started 17 Aug. 1912, 4:45 P. M.
Ended 18 Aug. 1912, 8:00 A. M.

At start —Bar. =740 m.m.; Temp. =19.3° C.
At end — " =734 m.m.; " =20.4° C.

| Ext. = Left-hand system ($CS_2$—treated). | Ext. = Right-hand system (no treatment). |
|---|---|
| Gas-burette reading | Gas-burette reading |
| 27.5 c.c. | 20.5 c.c. |
| 30.5 | 23.5 |
| 27.5 | 20.5 |

Readings reduced to 760 m.m. mercury pressure and 0°C:—
Left-hand system ($CS_2$—treated).

430 c.c. = Volume of left-hand system, exclusive of gas-burette.
27.5 c.c. = Volume of gas in left-hand gas-burette.

457.5 c.c. = Total volume of left-hand system at start.

$$\frac{457\ (740-16.655)273}{760(273+19.3)} = 406.6 \text{ c.c. vol. at start (reduced).}$$

430.0 c.c.
30.5

460.5 = Total vol. at end of test; before $CO_2$ had been absorbed.

$$\frac{460.5\ (734-17.826)273}{760(273+20.4)} = 403.7 \text{ c.c. Vol. before } CO_2 \text{ had been absorbed (reduced).}$$

430.0
27.5

457.5 = Total vol. at end of test (after $CO_2$ was absorbed).

$$\frac{457.5(734-17.826)273}{760(273+20.4)} = 401.1 \text{ Vol. at end of the test (reduced).}$$

Then 406.6
401.1

5.5 c.c. $O_2$ absorbed during test by the "extract plus hydroquinone" in the presence of $CS_2$ — vapor in air.

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and 403.7
401.1

2.6 c.c. $CO_2$ given off during test in the $CS_2$ —treated gas-container.

Right-hand System (check).
420.0 c.c. = Vol of right-hand system, exclusive of gas-burette (at start.)
20.5 = Vol. of right-hand system gas burette.

440.5

$$\frac{440.5(740-16.655)273}{760(273+19.3)} = 394.7 \text{ c.c. Vol. at start (reduced).}$$

420.0 c.c.
23.5

443.5 c.c. = Total vol. at end of test (before $CO_2$ had been absorbed.)

$$\frac{443.5(734-17.826)273}{760(273+20.4)} = 389.3 \text{ c.c. above vol. (reduced).}$$

420.0 c.c.
20.5

440.5 c.c. = Total vol. at end after $CO_2$ had been absorbed.

$$\frac{440.5(734-17.826)273}{760(273+20.4)} = 386.6 \text{ c.c. above volume (reduced).}$$

Then 394.7
386.6

8.1 c.c. $O_2$ absorbed during test by the check.

and 389.3
386.6

2.7 c.c. $CO_2$ given off during test by the check.

8.1 − 5.5 = 2.6 c.c. more $O_2$ absorbed in case of the check (i. e. not treated with $CS_2$ —vapor).

Note was kept of twenty-one experiments carried out in adjusting and in learning to manipulate and use the apparatus to obtain trustworthy results. It was found that the greatest care must be taken to be sure that the two systems of the apparatus were at the same temperature. A door, opened for a short time to admit air of a different temperature from one side of the room, could cause a variation in the volume of the gas in the two systems which would entirely vitiate results if readings were made at that time. It was discovered also that a variation in the influence of the insecticide-vapor occurred, depending on whether the extract were used immediately after it had been prepared, or not until a few hours later—this seemed to be especially true when gasoline was used. This fact served to emphasize the necessity of taking, from the prepared extract, the sample to be treated with the insecticide and the check sample at the same time, and of carrying out the tests with the two during the same period—although the reason for the variation mentioned above was not appreciated until later in the investigation. If the insecticide vapor in the air used in an experiment was near saturation, then it was necessary not to allow the room temperature to fall below that at which the experiment was started. Otherwise some of the insecticide-vapor would be condensed and the vapor tension of the gas-mixture changed. Correction for change in vapor-tension of water vapor due to a change in temperature could be readily made, but no method was at hand for making a similar correction in case of gasoline or carbon-disulphide vapor when the apparatus illustrated by Fig. I was being used. Furthermore, it was found that high concentrations of the insecticide

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vapor were necessary to show a marked influence, especially if the water content of the extract were high.

After the preliminary tests, written record was kept of more than thirty experiments, including cautionary check experiments, which were made to get the influence of gasoline and carbon disulphide vapors upon the oxygen absorption activity of "insect extract plus hydroquinone solution". Some of these experiments were performed during as many as three successive periods. In all of these tests unless otherwise stated, the stender dish of each gas-container held 5 c. c. of insect tissue extract from the same stock extract mixed with 2 c. c. of a standard hydroquinone solution (1.1 grams of hydroquinone in 100 c. c. of distilled water.) Representative results of these experiments are given in table II.

The first ten results in the table relate directly to the influence of carbon disulphide or of gasoline vapor upon the activity of "insect tissue extract plus hydroquinone solution" for oxygen absorption.

A study of the table will show that the higher concentrations of insecticide vapors caused a marked reduction in oxygen avidity under that shown by the corresponding checks. Weak concentrations of the insecticides, on the other hand, seemed to accelerate, very slightly, rather than to retard oxygen absorption. One may appreciate the influence of the insecticide, perhaps, better by comparing the total sum of the oxygen absorptions in the insecticide chamber with the total corresponding absorptions in the check gas-chamber.

In case of carbon disulphide vapor the ratio is 6.7 c. c. to 19.1 c. c. In other words, only about 7/20 as much oxygen was absorbed during the series of tests in the carbon disulphide chamber as was absorbed in the check gas-chamber with air alone present. For gasoline-vapor the ratio is 10.2 c. c. of oxygen absorbed in the gasoline chamber to 13.9 c. c. in the pure air chamber (i. e. about 7/10); and if those tests in which the vapor was in high concentration are considered alone, then barely over one-half as much oxygen was absorbed in the gasoline-vapor chamber. The ratio of carbon dioxide given off to the oxygen absorbed by the mixture of "insect tissue-extract and hydroquinone solution" as expressed by the totals for the insecticide-treated samples is 0.8+, and the similar ratio as expressed by the totals for the corresponding checks is 0.4. That is, the respiratory ratio of the "tissue-extract plus hydroquinone solution" proved to be decidedly higher in the presence of strong gasoline or carbon disulphide vapors than was found to be the case in pure air. Now, as has already been mentioned, an oxidase in the insect tissue-extract is able, it is believed, to accelerate the oxidation of hydroquinone to quinone and water—the quinone showing its presence by its odor and by a change in color of the extract-solution. If, then, an oxidase in the extract does cause that kind of an oxidation of hydroquinone, it would naturally follow that an extract to which the latter had been added might take up more oxygen in a given period than it otherwise would, and that the added hydroquinone would therefore decrease the respiratory ratio $\left(\frac{CO_2}{O_2}\right)$ of the extract. Note the ratio 0.4 above, which is much below that found for healthy beetles in pure air—the latter ratio being about 0.75. The last three results given in Table II are precautionary checks on the manner in which hydroquinone is oxidized by extract of the tissues of *P. cornutus*. To each of the stock

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TABLE II.—INFLUENCE OF GASOLINE AND $CS_2$ VAPORS UPON THE ABSORPTION ACTIVITY FOR OXYGEN OF INSECT TISSUE-EXTRACT PLUS M-10 HYDROQUINONE SOLUTION.*

*(1.1 grams of hydroquinone in 100 c. c. of dist. water.)

| Exp No. | Stock extract from:— | Insecticide. | Period. | Insecticide chamber. | | Check gas-chamber. | |
|---|---|---|---|---|---|---|---|
| | | | | $O_2$ used. | $CO_2$ given off. | $O_2$ used. | $CO_2$ given off. |
| 1. | 3 large white grubs and 20 c. c. water | $CS_2$, rather low concentration | 29 hrs | 5.5 c. c. | 2.2 c. c. | 6.4 c. c. | 1.6 c. c. |
| 2. | 3 white grubs, 15 c. c. water. (1 hr. old). | $CS_2$, high concentration | 21 hrs | 0.3 c. c. | 1.9 c. c. | 4.9 c. c. | 2.4 c. c. |
| 3. | 4 white grubs, 20 c. c. water (Ext. 5 hrs. old) | $CS_2$, nearly saturated | 16 hrs | 0.3 c. c. | 2.8 c. c. | 3.9 c. c. | 1.4 c. c. |
| 4. | 4 white grubs, 20 c. c. water (ext. 6 hrs. old) | $CS_2$, nearly saturated | 24½ hrs | 0.6 c. c. | 0.5 c. c. | 3.9 c. c. | 0.9 c. c. |
| | Totals | | | 6.7 c. c. | | 19.1 c. c. | |
| 5. | 1 large and 6 small white grubs, 18 c. c. water | Gasoline vapor, low concentration | 6 hrs | 1.9 c. c. | 1.3 c. c. | 1.8 c. c. | 1.3 c. c. |
| 6. | 8 *Allorhina* grubs, 20 c. c. water | Gasoline vapor, high concentration | 16 hrs | 2.5 c. c. | 2.0 c. c. | 4.5 c. c. | 4.0 c. c. |
| 7. | 6 *Allorhina* grubs, 20 c. c. water | Gasoline vapor about ⅔ concentration | 17 hrs | 2.1 c. c. | 2.8 c. c. | 3.3 c. c. | 2.3 c. c. |
| 8. | 6 large *Allorhina* grubs, 20 c. c. water | Gasoline vapor, low concentration | 4 hrs | 1.2 c. c. | 0.8 c. c. | 1.1 c. c. | 0.7 c. c. |
| 9. | 8 *Passalus cornutus*, 30 c. c. water | Gasoline treated | 8½ hrs | 0.6 c. c. | 1.0 c. c. | 1.6 c. c. | 0.4 c. c. |
| 10. | 8 *Passalus cornutus*, 30 c. c. water | Gasoline treated, but no insecticide present during the experiment | 16 hrs | 1.9 c. c. | 0.5 c. c. | 1.6 c. c. | 0.6 c. c. |
| | Totals | | | 10.2 c. c. | | 13.9 c. c. | |
| | | | | Check extract — no hydroquinone. | | Extract plus hydroquinone. | |
| | | | | $O_2$ used. | $CO_2$ given off. | $O_2$ used. | $CO_2$ given off. |
| 11. | 5 *Passalus cornutus*, 20 c. c. water | No insecticide used | 2½ hrs | 0.7 c. c. | 0.4 c. c. | 0.9 c. c. | 0.3 c. c. |
| 12. | 4 *Passalus cornutus*, 15 c. c. water | No insecticide used | 15 hrs | 0.7 c. c. | 0.4 c. c. | 3.4 c. c. | 1.0 c. c. |
| 13. | 4 *Passalus cornutus*, 10 c. c. water | No insecticide used | 6 hrs | 2.0 c. c. | 0.4 c. c. | 4.4 c. c. | 0.9 c. c. |
| | Totals | | | 3.4 c. c. | | 8.7 c. c. | |

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extracts (before samples for the tests were taken) four drops of weak ammonia (0.9 sp. gr. diluted five times) were added. This ammonia had the effect to reduce the carbon dioxide excreted to a very small amount.* The influence of oxidase in causing the hydroquinone to take up oxygen in the manner described might therefore stand out prominently. The total oxygen taken up and the total carbon dioxide given off in each case is given in the table, and although the ammonia used kept the ratio $\left(\frac{CO_2}{O_2} = \frac{1.2}{3.4}\right)$ down to 0.35 in the extract containing no hydroquinone, the value was brought down lower still $\left(\frac{CO_2}{O_2} = \frac{2.2}{8.7}\right)$ to 0.25 by the increased amount of oxygen used in the extract plus hydroquinone mixture. The larger value of the ratio $\frac{CO_2}{O_2} = 0.8$, as found above for the "extract plus hydroquinone" in the insecticide chamber, must therefore point to the fact that the gasoline and carbon disulphide vapors used were able in some unknown manner to inhibit or lessen the accelerating (catalytic) action of the extract-oxydase in bringing about the oxidation of hydroquinone. A further precaution which was observed should be explained here. Tissue-extract was brought to a boiling temperature (about 15 to 20 minutes) to destroy the oxidasic enzymes. It was then allowed to cool and the regular amount of hydroquinone solution was added. Tests were then made using the apparatus as in other experiments, and no measurable amount of oxygen was taken up during longer periods than any used in the regular experiments. It has already been explained that the hydroquinone stock solution would remain clear for days. However, if the heated "extract plus hydroquinone mixture" had been scarcely brought to the boiling temperature or had been heated only a short time before it was allowed to cool, it often showed a very slight reddish or cherry tinge after twenty-four to thirty hours—indicating that the heat had not been sufficient to destroy quite all of the oxidasic activity. Thus, the appearance of this peculiar reddish brown color was an even more delicate test of the oxidation of hydroquinone than the volumetric measurement of the oxygen used, and mention has already been made of how the reddish brown tinge deepened progressively as hydroquinone became oxidized to quinone. It was interesting and confirmatory, therefore, to note that in all ten of the experiments listed in table II the deeper color was found to be in the stender dish of that gas container where most oxygen had been taken up. One must see that in the extracts used, a slight respiratory exchange exists, and the influence of the insecticide agents upon this exchange has not been eliminated; but the respiratory exchange in such a treated extract (a few hours old) is very low indeed as shown by the $CO_2$ given off—and the evidence just enumerated leaves no doubt that in studying the comparable oxygen measurements, we see mainly the influence of the agents in question upon the oxidase activity toward hydroquinone. Two experiments (not recorded in table II), carried at once for short periods with gasoline vapor in high concentration, gave results contradictory to all the rest as far as gas measurements were concerned—that is, the measurements seemed to show that most oxygen had been taken up in the

*See effect of ammonia on $\left(\frac{CO_2}{O_2}\right)$. Tech. Bulletin 11.

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gasoline-treated chamber. Nevertheless, when run for longer periods afterward, the "extract plus hydroquinone" mixture in the gasoline chamber showed a reddish brown color not nearly so deep as that in the check gas-chamber containing air only, and the volumetric results then agreed with the results of the other experiments. The reason for the apparently contradictory results of the first and second parts of these two experiments was not understood until later. About a year and a half after these first experiments had been made (i. e. after the effect of gasoline upon the tissue reductase had been studied) it was decided to run a few more tests with gasoline-vapor, using a different method, in order to find out more surely if possible, the influence of this insecticide upon the absorption activity for oxygen of "insect tissue-extract plus hydroquinone" solution. The method decided upon was the old one (described in Part 1, Tech. Bull. II) in which the percentages of the gases present were determined at the beginning and at the end of the test period; but a different arrangement of gas-containers and gas- burettes was made to adapt the method to this problem.

The arrangement of containers and burettes in the apparatus used is represented in Fig. III. As may be seen, the apparatus is an adaptation of that shown in Fig. 1, with the circulating pumps and absorption flasks left out. There were two duplicate systems—gasoline-vapor-air was used in the gas-chamber of one system and pure air in the other. Hydroquinone burettes enabled one to introduce the hydroquinone as described in the case of apparatus Fig. I. The two gas-containers had each two two-way cocks, and these enabled one to adjust the mercury manometers and to take gas samples for estimation from each container at the beginning and at the end of test-periods. The gas-burettes permitted one to keep close check upon changes in gas-volume in each system, the readings being made at the known temperature and barometric pressure. From the percentage determinations (since the cubic contents of each system was known) one could figure the amount of oxygen used and of carbon dioxide given off at 760 m. m. pressure and O°C., as well as the exact percentage of gasoline to which the "insect-extract plus hydroquinone" solution had been subjected in the test. A set of results obtained with this arrangement of apparatus is given in table III. The total oxygen absorbed in the pure air chamber exceeded the total oxygen absorbed in the gasoline-air chamber, and the ratio $\frac{CO_2}{O_2}$ was a little higher in the gasoline-air chamber. By this method, as with the former method, however, it was found that if fresh extract were used for a short period, the result might be contradictory to that given for a much longer or for a later period with the same extract.

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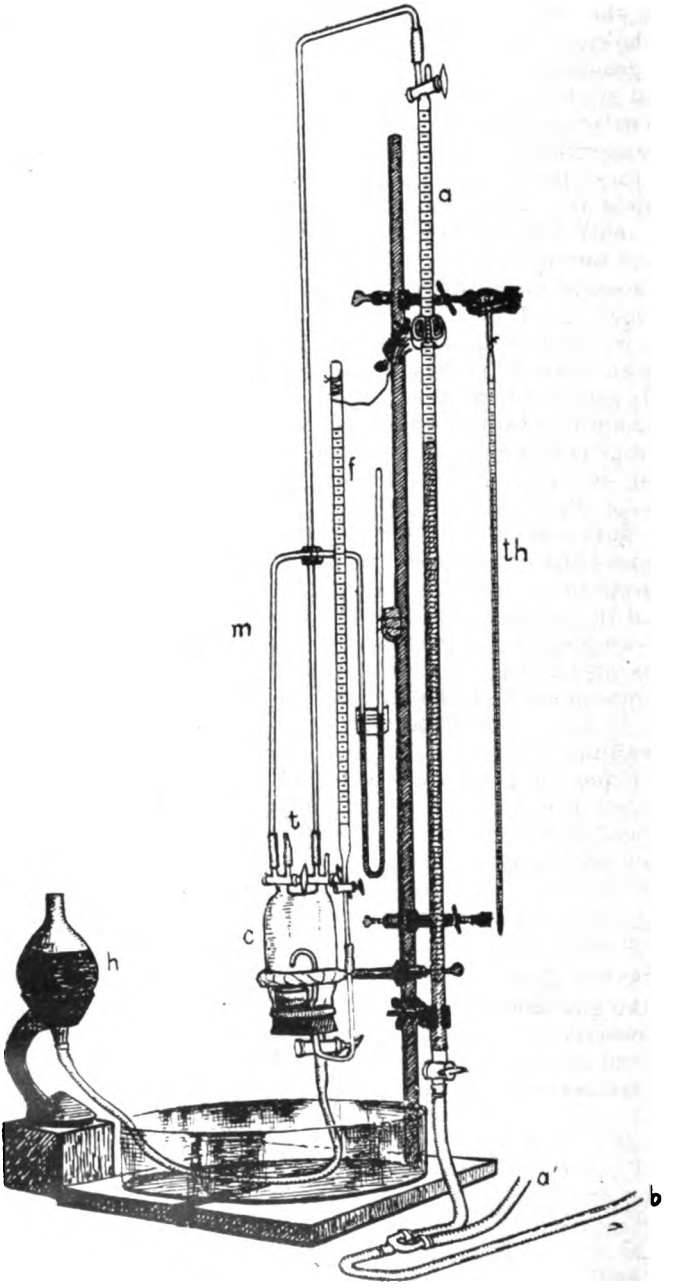


Fig. III. Shows half of a duplicate gas apparatus used for studying the influence of various agencies on certain activities of insects and insect tissue extracts: a = gas burette; b = rubber tube connected with mercury mug; a' = tube leading to duplicate gas burette; f = burette for hydroquinone solution or hydrogen peroxide or etc.; m = tube connecting gas container "c" with a mercury manometer; th.= thermometer; t = outlet of gas-cock.

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TABLE III.—EFFECT OF GASOLINE VAPOR ON THE AMOUNT OF OXYGEN ABSORBED BY INSECT TISSUE-EXTRACT PLUS HYDROQUINONE-SOLUTION.

(Method of percentage estimations).

| Exp. No. | Stock extract from:— | Gasoline vapor. | Period. | Insecticide chamber. | | Check gas chamber. | | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | | | $O_2$. | $CO_2$. | $O_2$. | $CO_2$. | |
| 1. | 8 *P. cornutus*, 20 c. c. water..... | 4.6%..... | 16½ hrs... | 2.2 c. c... | 0.6 c. c... | 2.8 c. c... | 0.1 c. c... | 0.6 c. c. more $O_2$ absorbed in the air chamber. |
| 2. | a. 9 *P. cornutus*, 15 c. c. water.... | 4.37%..... | 5 hrs..... | 2.69 c. c.. | 0.2 c. c... | 1.7 c. c... | 0.4 c. c... | 0.9 +c. c. more $O_2$ used in the gasoline chamber. |
| 3. | b. 9 *P. cornutus*, 15 c. c. water.... | ..... | 19 hrs.... | 2.3 c. c... | 0.96 c. c.. | 2.72 c. c.. | 0.5 c. c... | 0.4 +c. c. more $O_2$ used in the air chamber. |
| 4. | 9 *P. cornutus*, 15 c. c. water..... | 6.7%..... | 17 hrs.... | 2.7 c. c... | 0.4 c. c... | 2.9 c. c... | 0.5 c. c... | 0.2 c. c. more $O_2$ used in the air chamber. |
| 5. | a. 15 *P. cornutus*, 22 c. c. water... | 6.96%..... | 6 hrs..... | 1.31 c. c.. | 0.9 c. c... | 1.73 c. c.. | 0.39 c. c.. | 0.42 c. c. more $O_2$ used in pure air. |
| | b. 15 *P. cornutus*, 22 c. c. water... | ..... | 14½ hrs... | 0.72 c. c.. | 0.0 c. c... | 1.6 c. c... | 0.9 c. c... | 0.88 c. c. more $O_2$ used in the pure air. |
| | 15 *P. cornutus*, 22 c. c. water..... | 5.9%..... | 17 hrs.... | 1.1 c. c... | 0.72 c. c.. | 1.6 c. c... | 0.52 c. c.. | 0.5 c. c. more $O_2$ used in pure air. |
| | Totals..... | | | 13.02 c.c.. | 3.78 c. c.. | 15.05 c.c.. | 3.31 c. c.. | |
| | Totals, leaving out No. 2, a..... | | | 10.33 c.c.. | 3.58 c. c.. | 13.35 c.c.. | 2.91 c. c.. | |

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This is illustrated in table III by No. 2, where in the first five hours, the fresh extract used 0.9 c. c. more $O_2$ in the gasoline chamber than was used by its duplicate sample in pure air. When the same samples had then run undisturbed for nineteen hours, it was found on the other hand, that the pure air sample had taken up the most oxygen by 0.4 c. c. In No. 4 the stock extract was about five hours old when the samples were taken for the tests. Note that in this case, while the first test period of six hours showed more oxygen used in pure air, the longer second period gave an increased excess of oxygen used by the pure air sample. These results, taken with those obtained by the former method, seem to justify the conclusion that carbon disulphide and gasoline inhibit or lessen the rate of oxidation of hydroquinone in solution in the tissue extract of *Passalus cornutus*. Furthermore, in the case of gasoline, the effects on the rate of oxidation are not marked, unless the extract is a few hours old at the beginning of the test; and if perfectly fresh extract is used for a short period the results may be contradictory—apparently. As has already been mentioned, however, the series of experiments, results of which are recorded in Table III, were run after a study had been made of insect tissue reductase and of the effect of gasoline upon the reductase. This latter study, it is believed, affords an explanation of the apparantely contradictory results obtained when gasoline-vapor acts for short intervals upon freshly made "insect-tissue extract plus hydroquinone" solution. (See page 28.)

### (b) INFLUENCE UPON THE REDUCING ACTIVITY.

Some evidence has already been given of the existence of a strong reducing power in the fresh extract of *Passalus cornutus;* namely, the reduction (when air is excluded) of the dark melanic pigment which develops in the extract through the influence of the oxidasic enzymes when tissue-extract has been exposed to the air for a while, and the reduction of methylene blue to leuco-methylene blue when air is excluded from extract to which a little methylene blue has been added. Still other evidence may be given. If comparatively fresh "extract plus hydroquinone" which has already oxidized enough of the hydroquinone to quinone to give the solution a reddish-brown hue, is then confined in the absence of air or free oxygen for a few hours, the reddish-brown quinone will all be reduced; and if a little perfectly fresh extract is added before excluding the air, the reduction takes place more rapidly. Fresh extract stained blue with a little indigo carmine will reduce the stain to leuco-indigo carmine in the absence of free oxygen; and then, the reduced color body will oxidize and turn the extract solution blue again, if air is admitted—just as happens also when confined extract, holding leuco-methylene blue, is once more exposed to the air. After fresh extract has caused alcoholic guaiac to be oxidized to guaiac blue, if the entire mixture is then confined from free oxygen, the reducing bodies show their presence by reducing all guaiac-blue back to its former condition. Likewise, after tyrosin has been oxidized to the black melanic pigment, the latter can then be reduced by the extract, if air is excluded. In every case after reduction, oxidation may again be brought about if the confined extract containing the reduced body is once more exposed to air.

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It should be explained here, perhaps, that the strength and persistence of the reduction-activity varied a little with different lots of beetles, and that it always seemed to be best in the case of beetles showing the greatest strength and vitality.

Before discussing the effect of temperature, gasoline and other agencies upon the reductase, it will be best to describe briefly the method used in confining insect tissue-extract in the absence of air so that a study of its reductase activity under the influence of the various agents and conditions could be carried on in a manner which would permit of comparisons being made. As a rule, it was necessary to use small amounts of the extract and a method was needed by which the air could be excluded as completely as possible—and excluded quickly. After various means had been tried, the following plan was found to serve well. Small glass tubes of the same diameter and of practically the same length were heated and drawn out at each end to a fine capillary bore. The extract to be studied could be quickly drawn up to fill a tube, and then the capillary ends could be sealed at once by touching them in a hot gas flame. Fig. 2, Plate I, is a photograph of such a sealed tube. Methylene blue was the "substrate and indicator" most often used in making a study of the reduction activity. A standard solution of 0.1 gram of methylene blue in 100 c. c. of distilled water was employed. Unless otherwise stated in giving the results, six drops of this standard solution from the methylene blue pipette were used to 4 c. c. of the extract. (In most cases this ratio was found to be best.) The stain was thoroughly mixed with the extract and then the extract was divided into two equal parts—the one part to be treated for a certain time with the insecticide and the other, held as a check. Or, if two equal portions of the extract were taken at first, an equal number of drops of the standard methylene blue was added to each from a graduated pipette at practically the same time. At the end of the treatment period both parts were again shaken until they became a uniform blue. Then, from the treated and untreated stained extracts, tubes were quickly drawn full and sealed. Note was made of the period of time required for each tube to become reduced entirely free of the blue color. The time intervals given by this method for tubes of treated and untreated extract thus furnished the means for an instructive study of the influence of insecticides (or temperature, etc.) upon the reductase activity of any extract. Methylene blue showed a very slight deteriorating influence upon the reductase, it was found, but in the method this is not to be regarded since the stain was added to the treated (with insecticide) and the untreated portions of the extract at the same time in equal amounts as explained—all other conditions being the same for both portions of the extract, except the one condition under consideration.

By this method the influence of temperature, chloroform, ether, alcohol, gasoline, formaldehyde, carbon disulphide, hydrocyanic acid gas, toluol, ammonium formate, sodium fluoride, borax, mercuric chloride, pyrethrum, to-bak-ine and white hellebore was studied. Representative results are given in Table IV where the ratio between the time required to reduce methylene blue in the check and the time requird in the case of the treated extract may easily be obtained.

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TABLE IV.—INFLUENCE OF CERTAIN INSECTICIDE AGENTS ON THE REDUCING ACTIVITY (ON METHYLENE BLUE) OF EXTRACT FROM THE TISSUES OF *PASSALUS CORNUTUS*.

(Solution of Meth. Blue =0.1 gram in 100 c.c. of dist. water.)

| Exp. No. | Agent. | Time extract was treated before being drawn into tube and sealed. | Time required to reduce Methylene Blue in the treated extract. | Time required to reduce Methylene Blue in the check extract. |
|---|---|---|---|---|
| 1. | Gasoline, 0.5 c.c. to 4 c.c. of the extract | 10 min | 35 min | 7 min. |
| 2. | Gasoline, 1.0 c.c. in 3 c.c. of the extract | 3 min | 17 hrs. | 14 min. |
| 3. | Carbon disulphide, 0.5 c.c. in 3 c.c. of extract | 3 min | 1 hr., 16 min. | 14 min. |
| 4. | Carbon disulphide, 0.5 c.c. in 3 c.c. of extract | 23 min | 3 hrs., 21 min. | 19 min. |
| 5. | Alcohol, 0.5 c.c. to 2 c.c. of extract | 5 min | 6 min | 1½ min. |
| 6. | Alcohol, 0.5 c.c. to 2 c.c. of extract | 15 min | 10 min | 2 min. |
| 7. | Chloroform, 0.5 c.c. to 2 c.c. of extract | 5 min | 48 min | 8 min. |
| 8. | Ether vapor, saturated | 35 min | 5 min | 7 min. |
| 9. | Ether, 0.5 c.c. in contact with 2 c.c. of the extract | 5 min | 17 min | 9 min. |
| 10. | Formaldehyde (40%) 3 drops in 2 c.c. of extract | 5 min | Still quite blue after 24 hrs. | 10 min. |
| 11. | Tobakine, 1 drop to 2 c.c. of extract | 5 min | 10 min | 10 min. |
| 12. | HCN., (from KCN and $H_2SO_4$) strong charge 10 min. [aired 20 min.] | 10 min | 30 min | 4 min. |
| 13. | Treated in a very strong Cyanide bottle, 2 hrs. (aired 5 min.) | 2 hrs | 1 hr., 50 min. | 55 min. |
| 14. | Beetles treated for 15 hrs. in Cyanide bottle, and then aired ½ hr. before extraction | | 18 min | 4 min. |
| 15. | Toluol, 3 drops to 2 c.c. of extract | 4 min | 5½ min | 2½ min. |
| 16. | Toluol (same as above) | 15 min | 30 min | 15 min. |
| 17. | Pyrethrum, 0.5 c.c. dry powder to 2 c.c. of extract | 5 min | 4 min | 1½ min. |
| 18. | Pyrethrum (same as above) | 27 min | 38 min | 6 min. |
| 19. | Pyrethrum (same as above) | 2 hrs | 18 hrs. | 1 hr., 25 min. |
| 20. | White Hellebore, 0.5 c.c. dry powder to 2 c.c. extract | 5 min | 4½ min. | 3 min. |
| 21. | White Hellebore (same as above) | 10 min | 16½ min. | 5 min. |
| 22. | White Hellebore (same as above) | 97 min | Between 16 and 18 hrs. | 1 hr., 40 min. |
| 23. | $HgCl_2$, 1 drop of saturated solution in 2 c.c. of extract | 5 min | No apparent reduction at all | 20 min. |
| 24. | NaF (sat. solution), 1 c.c. to 3 c.c. of extract; 5 drops of Meth. Blue | 8 min | 6 min | 3 min. |
| 25. | NaF (sat. solution), 1 c.c. to 3 c.c. of extract; 5 drops of Meth. Blue | 25 min | 8 min | 10 min. |
| 26. | NaF (sat. solution), 1 c.c. to 3 c.c. of extract; 5 drops of Meth. Blue | 65 min | 21 min | 1 hr., 50 min. |
| 27. | Borax (3 grms. in 100 c.c. water), 0.6 c.c. to 2 c.c. of extract | 10 min | 27 min | 10 min. |
| 28. | Borax (3 grms. in 100 c.c. water), 0.6 c.c. to 2 c.c. of extract | 30 min | 1 hr., 50 min | 46 min. |
| 29. | Am. Formate, 1 c.c. of $\frac{M}{1000}$ solution to 2 c.c. of extract | 5 min | 15 min | 5 min. |
| 30. | Temperature 58° C | 5 min | About 10 hrs. | 2 hrs. |
| 31. | Temperature 0° F. for 3 hrs | | After first warming, 3½ min. | Average of fresh extract, 1½ min. |
| 32. | Temperature 70° F. stood for 3 hrs | | 6 hrs | 1 min. |
| 33. | Carbon tetrachloride, 4 drops in 4 c.c. of extract | 15 min | 70 min | 18 min. |
| 34. | Air saturated with vapor of carbon tetrachloride at 70° F | 40 min | 3¼ hrs. | 1½ hrs. |

The results as given here are designed only to show whether the influence of the agent upon the reducing power of the extract is marked or not. The reducing activity of the tissue extract of *P. Cornutus* may be entirely destroyed by a continuous temperature of 100° C. for ten to fifteen minutes. While this high continuous temperature is necessary for *complete* destruction, the greater part of the activity is quickly lost

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at 58° to 60° C. A low temperature tends to conserve the reducing activity—indeed, it serves, at once, to conserve and to inhibit the reducing power of the extract. No. 31 of Table IV gives a trial with extract kept for three hours at 0° F. When this extract was quickly but gently warmed to room temperature, it reduced methylene blue in 3½ minutes, whereas extract that had stood exposed to the air at 70° for three hours required six hours to reduce the color. The checks of fresh extract at the beginning reduced the same amount of methylene blue in one minute and in 1½ minutes. The reducing activity of fresh extract seems to be best at a room temperature of about 70° to 80° F., but it rapidly deteriorates during the first five to six hours after extraction (at the room temperature) and gradually, more slowly afterward. This is true even when the fresh extract is confined from the air. For example, a certain check of perfectly fresh extract reduced its methylene blue more than six times faster than another portion of the extract (A) which was tested after its confinement from air for 1½ hours from the moment of its extraction. Nevertheless "A" was 2½ times faster in reducing its methylene blue than a third portion (B) of the same extract which had been exposed to the air during the 1½ hour period. One might think from this that confinement from air tended to conserve the reducing activity. It is necessary to remember, however, that a dark melanic pigment developed in any extract (as "B") exposed to the air, due to the influence of the oxydase present, and that a portion (as A) confined from air could develop no pigment. When "A" and "B" were finally given the reduction-test with methylene blue, then (at the end of 1½ hours in this example), the reductase in "A" had only methylene blue to reduce while that in "B" attacked the dark pigment as well as the methylene blue. It seems likely, therefore, that the longer time for the reduction of the methylene blue was required by "B" because of the greater work in reducing the melanic pigment in addition to the methylene blue, rather than because its reducing activity had become less than that in "A".

Mention has already been made of the fact that when fresh extract is exposed to the air, it darkens first, only in a thin film at the surface. Also, if the fresh extract is allowed to stand after it has been stained with methylene blue and shaken so that the color is uniform throughout, it will be but a few minutes until the surface only will be blue—a reduction of all color in the deeper portions of the container having taken place. After a time, however, the blue coloration will begin—slowly at first and then more and more rapidly—to extend deeper into the container; in the case of the unstained extract, the dark melanic pigment will gradually form more rapidly as time goes on. It was soon found that this increased rapidity in the reoxidation of the methylene blue and in the formation of the melanic pigment coincided or tallied with the deterioration in the activity of the reductase of the extract on standing. That is to say, when the extract was new and its reductase still remained strong, it visibly held in check the work of the oxydase in the same extract. This proved as well to be the case when alcoholic guaiac or hydroquinone solution was used in the extract as the agent to be oxidized. Now, as may be seen by Nos. 1 and 2 of Table IV, gasoline was found to be quickly and strongly deleterious to the reducing activity of

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fresh extract of *Passalus cornutus*. The influence of strong gasoline-vapor upon the reductase was decided and much more marked than any influence upon the oxidase-activity—furthermore, the resultant-effect of gasoline-vapor upon the oxidasic action in very fresh extract was plainly due, in part, to the deleterious effect upon the reductase, since the latter was an inhibitor of the oxidasic processes. It was evident that in nearly elminating the reductase activity in the treated portion of a *fresh* extract, gasoline-vapor removed at once a greater inhibiting influence upon oxidasic action than it could itself exert—while in the check portion of the extract this inhibiting influence of the reductase continued for a few hours until it gradually disappeared through standing. Hence, a short period test of oxidase activity was sure to show that most oxygen had been taken up by the gasoline treated portion of a *fresh* extract. On the other hand, when the test with gasoline-vapor was made with extract that was a few hours old before the test began (and had thus already lost its strong reduction-activity) the inhibiting influence of the gasoline-vapor upon oxygen absorption in the "extract plus hydroquinone" solution became readily apparent in either long or short period tests. Thus, an explanation was afforded of those apparently contradictory results obtained when studying the action of gasoline-vapor upon hydroquinone-oxidase activity.

Table IV hardly shows the true extent of the deleterious effect of carbon disulphide upon the reduction-activity of fresh extract—since, in making check studies, it was found that methylene blue was slowly reduced by carbon disulphide alone, in the absence of air. However, that insecticide had little or no effect on indigo carmine, and when the latter was used as the test agent (½ grm. in 100 c. c. dist. water), it appeared that carbon disulphide was much more decidedly harmful to the reduction-activity of the extract than the study with methylene blue would lead one to believe.

It will be noticed from the table also that the amount of ether-vapor taken up by a water extract seemed to slightly increase or stimulate the reduction activity—whereas a small amount of liquid ether shaken up in the extract brought about noticeable deterioration in the reduction power. On the other hand, immediately upon being added in small amounts, a slight drop in the reduction-activity was caused by sodium fluoride, but after that it tended very markedly to preserve the reducing power of an extract (Nos. 24, 25 and 26 of Table IV).

The table (IV) itself, perhaps, gives sufficient explanation of the results for the remainder of the agents tested in this connection.

### (c) EFFECT UPON THE CATALASES.

Brief mention has already been made of the presence of soluble and insoluble catalases in the tissue-extract of *Passalus cornutus*. Loew found that the alpha (i. e. insoluble) catalase of tobacco was slightly soluble in water after a time, and this appears to be true of the corresponding catalase in the insect tissue extract. The soluble and insoluble catalases seem to be affected alike by heat and other agents, except that the insoluble form is a little more resistant in most cases. The tissue-pulp or crude water extract of *P. cornutus* may be dried without destroying the ability to liberate oxygen from hydrogen peroxide, but

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long continued drying injures that ability. A temperature of 59° C. for 10 minutes is sufficient, usually, to destroy almost all the catalase activity in the pulp or crude water-extract from this beetle, leaving the oxydasic power of the same pulp or extract still very active toward guaiac or tyrosin. Sometimes an extract was found to show a little greater resistance to heat; and in any case, if one wished to be sure of destroying absolutely all catalase activity toward hydrogen peroxide, so that small bubbles of oxygen would not appear even after several hours, a temperature very near the boiling point was required. It was possible to separate the soluble catalase from its solution but not to free it from proteins. The catalase was carried down with the protein precipitate by either half or full saturation with ammonium sulphate or with the precipitate by alcohol; and the precipitate from *full saturation* with ammonium sulphate was found to contain practically all of the catalase.

In making a quantitative study of the influence of insecticide agents on the catalases one could obtain a little more uniformly constant results by using a fairly clear solution in which any insoluble particles present would be extremely fine, so that they would remain in suspension for hours. The results given in Table V are therefore taken from a study of the influence of certain agents upon the catalases in such an extract solution from the tissues of *P. cornutus*. The beetles were extracted in the usual way (i. e. digestive tract removed, etc.), using distilled water at the rate of about 12 c. c. to 5 beetles. The crude extract was filtered through linen of very fine mesh. Two cubic centimeters of this filtrate were then measured out and diluted to 10 c. c. with distilled water. In this way an almost clear dilution was obtained in which the fine particles remained in suspension for hours; and by agitating the dilution just before dividing it, one could obtain entirely uniform samples. In every test, 2 c. c. of this diluted extract were measured out into a small stender dish and submitted to the treatment under consideration for the required time. A check of 2 c. c. was also measured out. In some cases where gases or vapors were used, the stender dish with treated extract was allowed to air for a certain period before the final test with hydrogen peroxide was made. For measuring the amount of oxygen liberated from hydrogen peroxide by the treated portion of the extract and by the check, the apparatus represented in Fig. III was used. As has already been explained, this apparatus was in duplicate so that the test with the treated extract could be run in one and the check in the other duplicate. After the stender dish of extract had been introduced into the gas-container. mercury seal was made at the mouth of the container. The mercury manometer was adjusted level, and the reading of the gas-burette taken. Then 5 c. c. of hydrogen peroxide were drawn in form burette "f". As oxygen was liberated and the volume of the gas in the container increased, the mercury in the gas-burette was lowered until the manometer was once more level just at the end of 10 minutes. Then the reading of the gas-burette was again taken. The increase in volume less 5 c. c. (i. e. 5 c. c. of $H_2O_2$), represented, the oxygen liberated. Any variation in the volume of oxygen liberated by the treated extract from the volume liberated by the check, therefore, was due to the influence of the treating agent, since all the other conditions were the same for both extracts. After an extract was

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TABLE V.—INFLUENCE OF INSECTICIDE AGENTS ON THE CATALASES FROM TISSUES OF *P. CORNUTUS*.

| Exp. No. | Agent. | Time agent was used. | After treatment. | $O_2$ liberated from $H_2O_2$ by treated ext. in 10 min. period. | $O_2$ liberated from $H_2O_2$ by check in 10 min. period. | Ratio of treated to untreated. |
|---|---|---|---|---|---|---|
| 1. | Strong Cyanide bottle | 17 hrs. | Aired 5 min. | 5.5 c. c. | 55.0 c. c. | 0.1 |
| 2. | Strong Cyanide bottle | Same 17 hrs. | Aired 2 hrs. | 17 c. c. | | 0.3 |
| 3. | Strong Cyanide bottle | Same 17 hrs. | Aired 8 hrs. | 26.2 c. c. | 55.0 c. c. | 0.47 |
| 4. | $CS_2$ (Air—Sat. vapor) | 2 hrs. | 15 min. | 2.0 c. c. | 55.0 c. c. | 0.03 |
| 5. | $CS_2$ (Air—Sat. vapor) | Same 2 hrs. | 16 hrs. | 1.0 c. c. | 55.0 c. c. | 0.01 |
| 6. | Air sat. with gasoline vapor, 4½% | 1 hr. | | 40.0 c. c. | 38.0 c. c. | 1.05 |
| 7. | Air sat. with gasoline vapor, 4½% | 16 hrs. | | 36.0 c. c. | 36.0 c. c. | 1.0 |
| 8. | Carbon tetra-chloride vapor. Sat. air | 16 hrs. | Aired 10 min. | 56.5 c. c. | 62.0 c. c. | 0.92 |
| 9. | Carbon tetra-chloride vapor. Sat. air | Same 16 hrs. | Aired 1½ hrs. | 57.5 c. c. | 62.0 c. c. | 0.94 |
| 10. | Chloroform vapor (air sat. at 68° F.) | 16 hrs. | Aired 5 min. | 40.5 c. c. | 50.0 c. c. | 0.81 |
| 11. | Chloroform vapor (air sat. at 68° F.) | Same 16 hrs. | Aired 5 hrs. | 41.5 c. c. | 50.0 c. c. | 0.83 |
| 12. | Ether vap. air sat. at 68° F. | ¼ hr. | 20 min. airing. | 60.5 c. c. | 60.0 c. c. | 1.0 |
| 13. | Ether, 0.5 c. c. shaken up with 2 c. c. of ext. | 15 min. | Aired 2 hrs. until ether was evaporated. | 58.0 c. c. | 59.0 c. c. | 0.98 |
| 14. | Ammonia (0.9 sp. gr. —2 c. c. diluted to 100 c. c.) 0.5 c. c. of dilution to 2 c. c. of ext. | 5 min. | | 47.2 c. c. | 56 c. c. | 0.84 |
| 15. | Am. vap. (100 c. c. air sat'd. from 5 c. c. am.—water of 0.9 sp. gr.) | 1 hr. | Aired 30 min. | 0.5 c. c. | 56 c. c. | 0.008 |
| 16. | Tobakine, 1 drop to 2 c. c. of ext. | 10 min. | | 65.0 c. c. | 63.5 c. c. | 1.02 |
| 17. | Tobakine, 1 drop to 2 c. c. of ext. | ½ hr. | | 54.0 c. c. | 61.0 c. c. | 0.88 |
| 18. | Alcohol abs., .05 c. c. to 2 c. c. of ext. | 10 min. | | 50.0 c. c. | 49.0 c. c. | 1.02 |
| 19. | Alcohol abs., .05 c. c. to 2 c. c. of ext. | 60 min. | | 48.0 c. c. | 53.5 c. c. | 0.89 |
| 20. | Alcohol abs., 1 c. c. to 2 c. c. of ext. | 45 min. | | 4.8 c. c. | 53.5 c. c. | 0.089 |
| 21. | $HgCl_2$, 1 drop of sat. sol. to 2 c. c. of ext. | 5 min. | | No measurable amount. | 54.4 c. c. | |
| 22. | 1 c. c. of N/100 HCl to 2 c. c. of ext. | 10 min. | | 2.5 c. c. | 54.0 c. c. | 0.04 |
| 23. | Same treatment as No. 22. | Kept cold 19 hrs. | | 0.8 c. c. | 54.0 c. c. | 0.01 |
| 24. | NaOH 0.2 c. c. N/100 to 2 c. c. of ext. | 3½ hrs. | | 35.5 c. c. | 32.5 c. c. | 1.09 |
| 25. | Am. Formate (M/1000) 1 c. c. with 2 c. c. of ext. | 20 min. | | 32.0 c. c. | 61.0 c. c. | 0.52 |
| 26. | Am. Formate (M/1000) 1 c. c. with 2 c. c. of ext. | 55 min. | | 31.0 c. c. | 61.0 c. c. | 0.50 |
| 27. | Formaldehyde 0.3 c. c. of 40% to 2 c. c. of ext. | 15 min. | | 0.5 c. c. | 41.0 c. c. | 0.01 |
| 28. | Heat 52° C. | 5 min. | | 47.0 c. c. | 54.0 c. c. | 0.87 |
| 29. | Heat 56° C. | 5 min. | | 13.0 c. c. | 54.0 c. c. | 0.24 |
| 30. | Heat 59° C. | 2 min. | | 11.0 c. c. | 61.4 c. c. | 0.17 |
| 31. | Heat 59° C. | 10 min. | | Amt. scarcely measurable. | 61.4 c. c. | |
| 32. | Pyrethrum powder, 0.5 c. c. by measure to 2 c. c. of ext. | 40 min. | | 23 c. c. | 51.0 c. c. | 0.45 |
| 33. | White Hellebore, 0.5 c. c. powder to 2 c. c. of ext. | 5 min. | | 57 c. c. | 55.5 c. c. | 1.02 |
| 34. | White Hellebore, 0.5 c. c. powder to 2 c. c. of ext. | 30 min. | | 53.5 c. c. | 55.5 c. c. | 0.96 |

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TABLE V.—CONCLUDED.—INFLUENCE OF INSECTICIDE AGENTS ON THE CATALASES FROM TISSUES OF *P. CORNUTUS*.

| Exp. No. | Agent. | Time agent was used. | After treatment. | $O_2$ liberated from $H_2O_2$ by treated ext. in 10 min. period. | $O_2$ liberated from $H_2O_2$ by check in 10 min. period. | Ratio of treated to untreated. |
|---|---|---|---|---|---|---|
| 35. | Borax (3 grms. in 100 c. c. water) 0.5 c. c. to 2 c. c. c. ext..... | Used 20 min. before testing.. | ..... | 49.0 c. c..... | 55.0 c. c..... | 0.89 |
| 36. | Borax (3 grms. in 100 c. c. water) 0.5 c. c. to 2 c. c. c. ext..... | ½ hr..... | ..... | 60.5 c. c..... | 61.4 c. c..... | 0.96 |
| 37. | NaF, 0.5 c. c. sat. sol. to 2 c. c. of ext..... | 15 min..... | ..... | 11.7 c. c..... | 60.4 c. c..... | 0.19 |
| 38. | NaF, 0.5 c. c. sat. sol. to 2 c. c. of ext..... | 45 min..... | ..... | 12.0 c. c..... | 56.0 c. c..... | 0.21 |

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a few hours old (i. e. after the reductase had become weak) there was little change in the catalase activity during the next 24 hours (or even 48 hours if the extract were kept covered at near freezing). On this account, it was not always necessary to run a check for each test in a series when treated extract-samples from the same dilution were used. Instead, a check could be made at the beginning of the series and another check held until the end. If a perfectly fresh extract were used, however, the checks had to be run more often, because the strong reductase present inhibited the catalase a little; and as the former weakened on standing, the catalase was able to liberate more oxygen in a ten-minute period. For example, in one extreme case, 2 c. c. of a fresh extract dilution gave (with 5 c. c. of hydrogen peroxide) in 10 minutes, 54.5 c. c. of oxygen, while 2 c. c. of the same dilution kept at 40° F. over night liberated 61 c. c. of oxygen in 10 minutes. In another case using the same method, 2 c. c. of a fresh extract-dilution liberated 32 c. c. of oxygen while its check 3 hours later (at room temperature) liberated 34 c. c. of oxygen. It should be added that *after* this rise due to the passing of the reductase activity, the ability to liberate oxygen from hydrogen peroxide gradually diminished during longer periods of time.

About 75 quantitative tests were carried out by the methods described above to determine the effects of certain insecticide agents upon catalase activity. Representative results of these tests are recorded in Table V.

In discussing the influence of hydrocyanic acid gas on the oxidasic activity of the insect tissue-extract toward alcoholic guaiac, it was stated that, when the test was made immediately after treatment, the guaiac turned blue very much more slowly than in the check. On the other hand when the treated extract was allowed to stand in the air for a while, the influence of the cyanide gas gradually passed off until the treated extract would oxidize the guaiac almost as rapidly as the check. In other words, there was a partial progressive recovery. Table V shows that this insecticide agent behaved in the same manner toward the hydrogen peroxide catalases. In the experiment, results of which are given in the table, a little more than 6 c. c. of extract was kept in a strong cyanide bottle for 17 hours. At the end of that time, it was removed to the open air. After airing only 5 minutes, a test was made with 5 c. c. of hydrogen peroxide and in the following ten-minute period 2 c. c. of this extract liberated only 5.5 c. c. of oxygen—the check, in the same time, liberated 55 c. c. of oxygen. After airing for 2 hours, 2 c. c. of the same treated extract liberated 17 c. c. of oxygen; and after standing in the air for 8 hours until almost all odor of the cyanide gas had disappeared, 2 c. c. of the treated extract caused 26.2 c. c. of oxygen to separate from the 5 c. c. of hydrogen peroxide in a ten-minute period —the check giving 55 c. c. of oxygen. Other tests gave similar results, so that there is no doubt of a partial, progressive recovery of the catalase activity toward hydrogen peroxide in an extract treated with cyanide gas upon standing in the open air. Furthermore, the results of these tests seemed to show that both the soluble and insoluble catalases in the dilute extract had been affected and that both had recovered the greater part of their activity after the passing of the poison. In order to make more certain that this was the case, a few experiments were tried in which hydrocyanic acid gas (from KNC + dilute $H_2SO_4$) was

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made to act upon the two catalases separately. The crude extract was filtered. Then the clear filtrate, containing the soluble catalase, was diluted and treated by the method already described. The residue on the filter was washed as nearly free from the soluble catalase as possible, after which it was shaken up in a small amount of distilled water. This water containing the insoluble catalase in suspension was then divided into equal samples to be treated as in the other experiments. Charges of hydrocyanic acid gas sufficient to render specimens of *P. cornutus* helpless and quiet in 3 to 4 minutes were used. Such a charge of cyanide gas is much stronger than that used in ordinary fumigation. The charges were applied 40 to 45 minutes. (This was a longer time than was really necessary to kill specimens of the beetle.) The experiments showed that over 95% of the activity of the soluble catalase and only about 52% of the activity of the insoluble catalase was suspended at the end of a 45-minute period. There was 88% recovery, or more, (after the treated extract stood 15 hours at about 34° F.) in case of the soluble catalase, and about 21% recovery of the activity of the insoluble catalase toward hydrogen peroxide. The insoluble catalase seemed to show the greater resistance, but once its activity had been hindered by the poison, greater permanent injury resulted than in the similar event with soluble catalase.

A number of tests were made to determine whether any such recovery of the catalases in an extract would obtain, after treatment with hydrochloric acid instead of with hydrocyanic acid gas. In preparing a treated extract and its check for this test, when 1 c. c. of $\frac{N}{100}$ acid was added to 2 c. c. of extract, then 1 c. c. of distilled water of the same temperature as the acid was added to the 2 c. c. check extract in order to keep the same dilution in the two portions. The tests were run in the apparatus already described. Numbers 22 and 23 in Table V show that $\frac{N}{100}$ hydrochloric acid was quite destructive to the catalase; and there was no apparent recovery, even upon long standing, if the treated extract and its check were kept at a temperature not far above freezing during the long period of treatment. Upon standing after the first decrease in catalase activity, three cases of increased activity for liberating oxygen from hydrogen peroxide *did* occur in some of the early tests with hydrochloric acid. However, the increase in these three cases was really brought about by decay which (in a warm room) the weak acid used did not entirely prevent, for long, in the extract. With the precaution of keeping the extracts in the cold (near freezing) during the treatment period, no example of increase in catalase activity at any time after treatment with hydrochloric acid, up to 19 hours, was observed. It may be added that the deleterious action of this acid upon the reducing power of the extract was not so great as it was upon the catalase activity.

The series of tests, results of which are recorded in Table V to show the effect of heat upon the catalases, are for short-interval periods only. Other experiments showed that when the treatment-period was lengthened, temperatures yet lower than 52° C. showed appreciable injury to the catalase activity. For example, at a temperature ranging from 45° to 46° C. for two hours, the ratio of the volume of oxygen liberated in

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a test by the heat-treated extract to that liberated by its check was $\frac{75}{86} = 0.87$.

Some of the agents readily showed a slight acceleration of the catalase action, when used in small amounts. Attention may be called to gasoline and alcohol in the table (V) as illustrating this fact. The manner in which some of the insecticides (especially gasoline) appear to hasten oxidasic activity because of their deleterious action on the reducing power, when they were first applied to fresh extract, has already been described. It seems very likely that the slight acceleration of the catalase-action, at first, when an extract was treated with small amounts of the above insecticides, may have (in part at least) much the same explanation. That is, small amounts of gasoline, alcohol, and perhaps a few others, in attacking the reductases deleteriously before they attacked the catalases, removed a stronger inhibiting influence over the catalase than they themselves exerted, so that a resulting initial acceleration of the catalase action immediately followed. *Strong* treatment with the insecticides, however, so greatly hindered the catalase (as well as the reductase) activity, that there was a lessening of the volume of oxygen liberated from hydrogen peroxide. In the case of alcohol the deleterious effect of strong or more prolonged treatment was quite decided. Nos. 18 and 20 of Table V show that while 0.5 c. c. of absolute alcohol added to 2 c. c. of extract caused more oxygen to be liberated from hydrogen peroxide after a period of 10 minutes treatment, 1 c. c. of alcohol in 2 c. c. of extract for 45 minutes before the test brought the ratio of oxygen liberated by the treated to that liberated by the untreated extract down to 0.089. That is, the stronger treatment not only overcame the lead of the first increase, but reduced the catalase activity much below that of the check. The effect of strong, prolonged treatment with gasoline vapor was not so marked; it was sometimes barely able to overcome the first lead or increase in catalase activity—(the lead or increase which was due, as has already been suggested, to the removal of the inhibiting reductases). This is illustrated by the two experiments recorded in Table V, Nos. 6 and 7. In no case of strong treatment with gasoline vapor was the amount of oxygen liberated brought much below that of the check.

Ammonium formate and ammonium oxalate were used in the series of tests because they are known to be products formed when hydrocyanic acid gas breaks down in air. Ammonium formate, in any amount tried, permanently injured the catalytic action of the extract toward hydrogen peroxide, as illustrated in the table (V). Ammonium oxalate, on the other hand, served to slightly accelerate the liberation of oxygen from hydrogen peroxide by the catalases.

The influence of the other agents, so far as tested, are either made clear in the table or may be referred to later in discussing powdered solid contact insecticides.

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## DO THE CONTACT INSECTICIDES UNDER CONSIDERATION ACT UPON OXIDASES, CATALASES OR REDUCTASES IN THE LIVING TISSUES OF INSECTS TO CAUSE DEATH?

The experiments just described showed that the contact insecticides under consideration did interfere with the activity of the oxidases, catalases and reductases in the tissue extract of *P. cornutus*. In the concentrated form, such insecticides affected all three of the enzymes (if they may be so called) but usually not in the same degree. It was clear that carbon disulphide, for example, affected the oxidases and catalases more strongly than it affected the reductases—while gasoline, on the other hand, had its most deleterious influence upon the reductases.

Trial showed that oxidases, catalases, and reductases existed in the tissue-extract of many caterpillars, pupae and adult moths, as well as in the adults and grubs of various beetles. Also, reference has already been made to the work of Batelli and Stern* in relation to oxydones in insects. These authors, in the same year (1913), again described tyrosine-oxidase, polyphenol-oxidase, and oxydones in several forms of insects. Besides, a few other scattered references in literature briefly (often covertly) relate the occurrence of oxidases in the blood or in extracts from various lepidoptera, beetles and diptera. Loew has recorded the presence of catalase in three different beetles. In fact, the occurrence of oxidases, catalases and reductases in extracts appears to be as general among insects as among other forms of life.

Further experiments showed that extracts from tomato-worms did not give the test for oxidase with alcoholic guaiac but hydroquinone-oxidase and tyrosin-oxidase were clearly present as well as reductases and catalases. Moreover, the influence of gasoline and carbon disulphide upon the activity of extracts from white grubs (both *Lachnosterna* and *Allorhina*) and tomato worms was similar to that already recorded in connection with extracts from specimens of adult *P. cornutus*.

With these facts established, the question remained as to whether oxidases, catalases and reductases in the *living* tissues of *P. cornutus* became deleteriously affected by contact insecticides used in such amounts and for such periods only as were necessary to kill. That catalases and reductases, as found in the tissue extract of the insect, really existed in the living tissues (and were not after-products of the tissues in the extract) seemed reasonably certain. If hydrogen peroxide were introduced directly into the tissues in any part of the body of a living beetle, oxygen became liberated *at once* with great energy; and the reducing power of living animal tissues, generally, for methylene blue is well known. In technical bulletin 11 (this station), page 52 is reference to the fact that living beetles, in the absence of oxygen gas, reduced large amounts of indigo carmine and methylene blue which had been injected into the body tissues by means of a fine hypodermic needle. Even in the open air, a small amount of methylene blue, injected into the tissues of a beetle's body, became entirely reduced. When the reduced (leuco-) methylene blue was collected for excretion by the cells of the Malpighian tubules, however, it became oxidized to the blue color again in those cells. Still, this reoxidation of the color-body did not neces-

*Batelli and Stern (Biochem. Zeits., 1913, 56, 59-77). Rev., J. of the Chem. Soc., Vol. 103-104, part i, p. 1272.



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sarily imply or prove the presence of oxidase activity, and no entirely satisfactory method of *visibly demonstrating* oxidase activity in the tissues of living uninjured insects was found. Upon studying the case, however, there was nevertheless found to be visible evidence of almost positive oxidase activity naturally present in certain living cells of most insects. The facts which set forth this evidence follow:—

The wing covers of newly emerged adults of *P. cornutus* were almost without color—pure white. They gradually began to brown, becoming darker and darker until they finally appeared jet black—and by that time, they were entirely dry and hard. When the dry, black wing covers were crushed and tested they were found to contain catalase and an (almost) insoluble tyrosin-oxidase (see Fig. 3, Plate I); reductase activity was practically absent. The dark coloring matter of the crushed wing-covers appeared to be identical with the dark pigment which formed when the insect-extract or blood was exposed to air. Moreover, this melanic pigment in both cases was like the melanic pigment obtained when tyrosin, in solution, was oxidized by insect tissue-extract. (Tyrosin is a protein derivative). The wing-cover pigment, as well as both the other pigments just mentioned, could be reduced by confining it in the absence of oxygen with fresh tissue-extract which was rich in reductase activity. The coloration of newly emerged insects could be entirely stopped at any stage by dropping the insects into boiling water and keeping them at that temperature for about 20 minutes. Again, if white, newly moulted insects (*Periplaneta Americana* was used) were submerged in $CS_2$ and kept there, almost no dark coloration developed. Also (as has been generally found by experience) in order to preserve white grubs and pupae in alcohol without darkening or discoloring, they first had to be treated with boiling water. That is to say, some means (such as heat) appeared to be necessary to destroy the oxidase activity before placing the white adults, grubs or pupae in alcohol; otherwise, the inhibiting action of the strong reductase, present in the living body, rapidly passed after death, and the oxidase (which is injured but not entirely destroyed by alcohol) then brought about oxidation and blackening of the tissues. Likewise, since an oxidase which could oxidize tyrosin was present in the wing-covers and outer integument of *P. cornutus* and the cockroach (*Periplaneta Americana*) it appeared that the cuticular excretion poured out from the hypodermal cells beneath the old integument before it became moulted—the excretion which *went to form* the integument of the newly moulted insect—contained not only the tyrosin-oxidase but also a tyrosin-like derivative (i. e. some similar organic derivative) which oxidized, under the influence of the oxidase, to form the brown or melanic coloration of the integument. These added instances of the activity of an oxidase did not, so far, prove its presence in living cells. The evidence showed, however, that in blood exposed to the air, in extract of the tissues exposed to air, in the cuticular integument of the newly moulted adult beetle and in the tissues of the dead grub and pupæ (killed by some means that does not destroy an oxidase) a very similar, if not an absolutely identical, melanic pigment developed under the influence of an oxidase in every case—and more rapidly as the reductase activity passed. Moreover, these instances of melanic pigment formation served to call to mind the fact that in certain cells of the

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compound eyes of insects, and of the ocelli of insects and spiders, and in the hypodermal cells forming the circular boundary of ocelli, there was to be quite commonly found a melanic pigment which had its origin *in the cells* during ontogenic development. In view of the proven cases of melanic pigment formation through oxidase action cited above, the inference that the development of melanic pigment in certain eye and hypodermal cells was an example of a similar oxidase acting upon some constituent of the cells, themselves, seemed to have justification. Other similar evidence might be given all tending to show that melanic pigment, in animal tissues, develops through the oxidation of some organic constituent of the tissues—under the influence of an oxidase* acting after the tissue-reductase has been either weakened or destroyed by some means.

In order, then, to learn something finally concerning the effect of a few contact insecticides (when used only in such amounts as were necessary to kill) upon oxidases, catalases and reductases in the living tissues of *P. cornutus,* the method of study was varied as follows:

Insects were killed by the insecticide agent to be studied, using various amounts of the agent for the length of time necessary to kill. The bodies were then extracted by the method already described, as soon as the insects were considered dead or beyond recovery, and the strength of the oxidase, catalase and reductase activities in this extract was compared with that in a fresh extract similarly prepared from the same number of untreated insects. Tests were made in this manner using heat, hydrocyanic acid gas, chloroform and carbon disulphide. It will be appreciated that it was impossible to check the factors of time, original strengths of catalase, oxidase and reductase in the extracts, etc. by this method as accurately as they could be checked in the former method where samples were taken at the same time, from a single extract, for study. Nevertheless, the results showed certain things very satisfactorily.

The extract from gasoline-vapor-killed beetles was always much weaker in reductase activity than the check, while the catalase and oxidase activity remained much the same. For example, when two beetles were treated with about 3% gasoline vapor for 20 hours, it required 4 hours for the treated extract to reduce a certain amount of methylene blue —the check accomplishing the same reduction in 10 minutes. Practically no difference could be seen in the rapidity with which alcoholic guaiac was oxidized; and a check-extract-sample liberated only 2 c. c. more of oxygen from the standard hydrogen peroxide than a similar sample-extract of the insects killed by gasoline.

The extract from beetles killed with carbon disulphide was always quite white or very light straw color at first and it remained so for two or three hours, usually, before it began to darken. That is, oxidase action always appeared to be almost entirely absent, at first. After a few hours, however, this activity became partly recovered. Catalase-action was usually injured one-half or more, and the reductase much less, so that it was relatively strong, at first, as compared with the oxidase activity.

Reductase in the extract of beetles treated 2½ hours with strong

*Hammarsten (Mandel) in his "Physiological Chemistry" quotes Fürth with Schneider and Prisbram, Gessard, Neuberg and Dewitz as having shown the presence of tyrosinases in insect-tissue and sepia, in melanotic tumors and in pigmented skin.

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chloroform-air was found to be, at the end of that time, 16½ times weaker than the check. The oxidase was apparently uninjured; sometimes it seemed a little more active than in the check. The catalase showed but little injury.

Hydrocyanic acid gas caused great interference with the activity of the oxidase. For example, three beetles were treated in a cyanide bottle 15 hours and then aired one-half hour before being extracted. This extract remained light or whitish in appearance for 2 hours before it began to darken at the surface in contact with the air, and before it would begin to show any indication of bluing guaiac. The check required only about 2 minutes to bring about a decided bluing of guaiac. The catalase-activity was quite strongly interfered with, at first; but the reductase required only about 9 times longer to reduce its methylene blue than the check.

Extract from beetles kept at 44° to 46° C. for 2½ hours, until dead, showed little loss in catalase activity—but more in its oxidasic and reductase activity. The oxidase was about 7 times slower, and the reductase about 21 times slower than the check.

Clearly, the results given by the last method corresponded very well with results obtained by the former method where the effect of the insecticide upon oxidase, catalase and reductase in the ready-prepared extract was studied. It is true that in every case the beetles were killed by the insecticide agent without the entire destruction of any one of the three enzymes—but never without greatly injuring one or more of them. Also, as will be observed, if the reductase were strongly injured, the oxidasic enzymes were usually little injured or apparently not at all; and conversely, if the oxidase and catalase were greatly injured by the insecticide, the reductase was little injured. Thus, the natural or normal balance of catalase, oxidase and reductase activity was disturbed.

The question may now be repeated: Is this deleterious effect of the insecticides studied, upon the oxidases, catalases or reductases, the cause of death? It is hardly possible that the three enzyme-like bodies named in the question could be so universally present (with activities so apparently coordinated) in tissue extracts and in the living tissues, if they were not of vital importance. They surely accomplish oxidations and reductions in the living tissues and much evidence indicates that they are a part, at least, of the machinery of internal respiration. It has been shown that *P. cornutus* cannot be killed or rendered beyond recovery, by certain contact insecticides studied, without decided injury to one or more of the three activities—oxidase, catalase or reductase. This fact, taken in connection with what has been shown to be true of the influence of those same insecticides upon the respiratory rate and the respiratory-quotient, supports the view that oxidase, catalases and reductases have to do with the starting and carrying forward of cell respiration. If that view is true, then the deleterious effect of the insecticides (named in this connection) upon oxidases, catalases or reductases in insects must be an important factor—perhaps, in some cases, the *determining* factor—in causing death.

No special study has been made of the influence of various contact insecticides upon the protoplasmic activities which carry forward life-processes in the nervous tissue cells of insects. Such a study in this connection would appear to be of next importance, since all the volatile

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insect fumigants are more or less narcotic in their action. Shiro Tashiro has found, by means of his new apparatus for estimating exceedingly minute quantities of carbon dioxide produced in nerve fibres, that ether and urathane "diminish $CO_2$ production from isolated nerve fibre"*—although he was not working with insects.

### CONCERNING THE INFLUENCE OF GASOLINE-VAPOR, ETC., AND LIME-SULPHUR SOLUTION UPON THE PASSAGE OF OXYGEN, RESPECTIVELY, THROUGH FAT OR LIPOID, AND CERTAIN WAX MEMBRANES.

It has been made clear that gasoline deleteriously affected the reductase activity far more quickly and severely than it did that of the oxidases; and further that, since the presence of a strong reductase tended to partly hold in check oxidase-activity, the quick lowering of reductase-activity in a gasoline-treated extract caused the latter to show greater oxidase power for a while than an untreated check of the same extract. This was true when the test was made with fresh extract in the presence of gasoline vapor. But in such tests as the last, made with extract that had already lost the greater part of its reductase-activity, the fact will be remembered that a less amount of oxygen was used by the "extract plus hydroquinone solution" (and less quinone was formed) in the presence of air containing gasoline vapor than by the check in pure air.

When an extract a few hours old was treated very strongly with gasoline and then test was afterward carried on in fresh air, however, oxidase activity did not appear to have been greatly lessened. The suspicion therefore presented itself that the lessened oxidation of hydroquinone occasioned by the extract in the presence of gasoline-vapor, as well as also the lessened use of oxygen by insects deeply under the influence of gasoline-vapor, was partly due to some other cause than injury of the oxidase or reductase by gasoline.

As has been mentioned several times, the first and most noticeable fact in connection with the tissues of an insect strongly treated with gasoline vapor, as well as with tissue-extract so treated, was the solvent action of the gasoline upon the fats and fat-like bodies (lipoids); or, looked at from the other point of view—the insistent fact was the solubility of the tissue-fats and lipoids for gasoline vapor. Lipoids were found to be present in or around the cells of insect tissues. For example, a semi-transparent lipoid residue was obtained by extracting the *washed* muscles of *P. cornutus* with ether containing a little alcohol. This was perhaps to be expected, since the almost universal occurrence of lipoids, especially such as lecithin, in animal cells and animal fluids has been recognized for several years. This lipoid residue obtained from the washed muscles of *P. cornutus* absorbed gasoline readily. The condition therefore seemed to obtain that wherever the lipoids might be found, in the body fluids (blood)—where they certainly were present—in the protoplasm boundary layer of the cells (Overton) or in the complex of the cell-protoplasm itself, gasoline would surely also be present in an insect under the influence of that insecticide. In any such case the insect tissue cells would be enveloped by blood holding gasoline in solution; the ends of the trachaeoles would be permeated by gasoline. Could

*Am. Jour. of Physiol., Vol. 32, 1913, No. 11, p. 117.
See also same Journal pp. 137-145.
See also same Journal Vol. 34, 1914, pp. 405-413.

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it be that this ready solubility for gasoline of the fats and lipoids of insect-tissues furnished a means for hindering the *absorption* of oxygen by the tissues, or lessening the oxidation of hydroquinone by the oxidase of insect-tissue extract in the presence of gasoline? It seemed that such might be the case, if in fact it should be found that gasoline, held in solution by fats and lipoids, lessened their solubility for oxygen—and by so doing, lowered the rate at which atmospheric oxygen might pass into an extract, or from the trachaeoles (or by any path) through the fluids bathing the cells, on into the cells to those agencies which (in life) utilize the incoming oxygen. Accordingly plans were made to determine what change the absorption of gasoline-vapor by a lipoid membrane, such as a lecithin membrane (or by a fat membrane) would have upon the rate at which oxygen passed through it. For the series of experiments to be made in this connection, it did not seem necessary or even desirable to use the fat or lipoids derived from insects. Clearly, the advantage would lie in eliminating all possible variable quantities. On that account, a comparatively pure fat and lipoid, each of which would be uniform and easily obtained, was desired. Several preliminary quantitative absorptions of gasoline-vapor, using definite amounts (3 grams) of lard, lanolin, lecithin, cholesterin, and (for comparison) egg-yolk and egg-albumen were first carried out. Some representative results of a few of these absorption tests are given in Table VI. The apparatus used was that represented by Fig. III, except that the hooked U-tube "u" and the burette "b" were not needed. The 3-gram quantity of lecithin (or eggwhite, etc.) was placed in a standard stender dish—so that the same absorbing-surface was exposed always—and the dish was then floated upon mercury in the gas-container "g. c." Most of the tests were made over rather short periods, during which the barometer and thermometer remained practically constant. Checks showed that in pure air the volume of gas enclosed with the absorbent (fat, etc.) which was being tested remained unchanged over similar periods of time. In the tests, a loss in volume as shown by the gas-burette was therefore the measure of the "gasoline-vapor" that had been absorbed. At the end of each test the percentage of gasoline-vapor still present was determined from a sample taken from the gas-container—using the "Nordhausen sulphuric acid" method of estimation already described in the former bulletin.

TABLE VI.—COMPARATIVE SOLUBILITY OF GASOLINE-VAPOR IN 3 GRAMS, RESPECTIVELY, OF LECITHIN, EGG-WHITE, ETC.

| Exp. No. | Material. | Temperature. | Per cent gasoline vapor at end of test. | Volume measure of gasoline-vapor absorbed. | Time used. |
|---|---|---|---|---|---|
| 1. | a. Lecithin | 22.2° C. | 3.0% | 2.7 c. c. | 30 min. |
| | b. Egg-albumen | 22.2° C. | 3.0% | 0.6 c. c. | |
| 2. | a. Egg-albumen | 24.1° C. | 3.0% | 0.7 c. c. | 40 min. |
| | b. Egg-yolk (fresh) | 23.7° C. | 3.0% | 0.1 c. c. | |
| 3. | Egg-yolk (fresh) | 25.0° C. | 3.5% | 0.1 c. c. | 60 min. |
| 4. | Cholesterin | 26.8° C. | 3.0% | 0.6 c. c. | 20 min. |
| 5. | Egg-yolk (fertile egg) after 4 days incubation | 24.0° C. | 4.4% | 1.0 c. c. | 60 min. |
| 6. | Egg-yolk (fertile egg) after 5 days incubation | 22.4° C. | 4.0% | 1.8 c. c. | 30 min. |

The lecithin (H. P. from egg, Merck) was used, as received from Merck, in the form of a paste; and in the case of cholesterin the soft dry powder

was used. The ready capacity of lecithin to absorb gasoline-vapor, from air containing it, is illustrated in the table. In connection with the solubility of egg-white for gasoline, it must be remembered that even egg-white is not pure albumen, but that it contains a mesh of extremely fine membranes of keratin and a very small amount of fats, lecithin, and cholesterin. The largest absorption of (3%) gasoline-vapor by 3 grms. of egg-albumen was that given in Exp. No. 2 (0.7 c. c.). A surprise came in finding the comparative solubility of fresh egg-yolk for gasoline-vapor as shown in the table. The results obtained in connection with fresh and incubated egg-yolk will be referred to again under the next heading.

After these preliminary tests and other trials, lard was selected as the fat and lecithin as the lipoid which seemed best adapted for the purpose (according to the plan mentioned above) of being spread into membranes to be used in determining the effect of gasoline-vapor upon their permeability to oxygen of the air. However, a few tests were made with membranes composed of a mixture of lard and lecithin, and also with lanoline membranes. All these membranes were prepared, and manipulated to obtain the results required by the plan, as follows:

A very light India muslin was used for the sustaining fabric, and over this the lecithin (or lard, etc.) was spread in a thin sheet entirely covering the fabric and filling its meshes to form essentially a lecithin (or lard, etc.) membrane. In making use of such a lecithin membrane, for example, it was placed as a cover over the mouth of a small preparation dish (4 cm. in diameter), which had been almost but not quite filled with concentrated lime-sulphur solution. The cover was then fastened down "lecithin tight" with a thin metal band, thus enclosing a small air space above the lime-sulphur in the preparation dish. Great care was used in order that the lime-sulphur might not wet the lecithin cover, and the dish was floated up on mercury in the gas container of the apparatus, Fig. III. In this position, the covered preparation dish was allowed to stand a few hours. Then the mercury manometer "m" was adjusted level. The thermometer and barometer readings, the time and the reading of the gas-burette "a" were all recorded. After a certain definite period all these readings were recorded again, the mercury-manometer having been first leveled once more through adjusting the height of the mercury column in the gas-burette "a". In this manner, the rate of volume-decrease of the air in the gas-container "c" was determined. The decrease was due to a decrease in the amount of oxygen in the air of the container holding the membrane-covered dish of lime-sulphur solution. This was definitely proven by determining the percentage of oxygen in the air from samples taken from the container immediately before the tests began and immediately after the last set of readings were recorded—the volume of air used in the container during the test being known. Since the conditions of the experiment have been outlined, it will be clear that this rate of decrease in oxygen was the rate at which oxygen was passing through the lecithin membrane—or whatever membrane was used to cover the preparation dish. From the beginning of the test, the lime-sulphur solution absorbed oxygen gradually and steadily from the small air-space above it. Just as constantly, oxygen was given off from the under side of the membrane (to the small air-space above the lime-sulphur) and *taken up* or *absorbed* by the upper surface of the membrane from the air of the container—the volume of which was

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comparatively large. The prime condition was (it will be remembered) that the lecithin cover (or lard, etc.) closed the preparation dish "lecithin tight." No oxygen could pass into the air space of the dish except it passed through the lecithin itself. When the rate at which oxygen passed through the membrane from air had thus been determined, the mercury mug "b" was raised, cocks "a" and "c" were opened and as much of the air as possible was carefully expelled.* Then, from a stock preparation, gasoline-air was drawn into the container as the mercury mug "b" was lowered. At first, gasoline-vapor was absorbed rapidly by the lecithin membrane. By making tests (as already described) at intervals, it was found that the rate of decrease in volume would finally settle down to a fairly uniform rate. That is, the membrane would finally become saturated with the gasoline-vapor, and the decrease in volume after that was due to the loss in oxygen absorbed by the lime-sulphur solution. This last rate was then determined as accurately as possible (just as has been explained when the cup was in air.) Here also, the direct method of measuring the loss in volume of oxygen could be checked by taking samples of gasoline-air at the beginning and at the end—making determinations of the percentage of gasoline and of oxygen present at each time and thus figuring the rate at which oxygen had been absorbed. Now this last rate in the loss of oxygen, it will be observed, was the rate at which oxygen passed through the same lecithin membrane after the latter had become saturated with gasoline-vapor in the presence of gasoline-vapor-air. The rate at which oxygen passed through the lecithin membrane in air might therefore be compared with the corresponding rate when the membrane was under the influence of gasoline-vapor. In many of the experiments, the covered preparation dish was taken from the container and aired until as much as possible of the gasoline-vapor had evaporated from the lecithin cover. After that the dish was carefully replaced in fresh air in the container and the rate at which oxygen passed through the membrane again determined. This was done, as a check, to learn whether the lime-sulphur solution was still in condition to absorb oxygen at a practically uniform rate when the membrane was exposed to pure air.. Further precautionary checks were made by finding the rate at which the uncovered dish of lime-sulphur absorbed oxygen in pure air and in gasoline air. These checks showed conclusively that at the end of the series of tests the lime-sulphur solution was still active enough to absorb oxygen much more rapidly than the lecithin or other membranes could take up that gas and pass it through to the absorbing solution, either in pure air or gasoline-vapor-air. In all cases, the temperature during any series of tests was kept as uniform as possible. When the thermometer or barometer changed appreciably, or whenever the tests extended over more than three hours, all gas-volume measurements were changed to 0° C, and 760 m. m. mercury pressure before comparisons were made.

Over 35 trial experiments were made with the apparatus in learning the best thickness of membrane to use, and the time-limits (in order that the lime-sulphur solution should not be weakened too much), as well as many other details. Thereafter, twelve series of tests were run to determine the influence of gasoline-vapor upon the rate of oxygen transfer

*The edge of the metal band, which was used around the top of the preparation dish to fasten the cover-membrane tightly, projected above the surface of the latter enough to entirely protect it from damage by the top of the container when the air was being expelled.

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through lecithin, lecithin-lard and lanolin membranes. The lecithin-lard mixture was made of about equal parts of lecithin and lard thoroughly mixed together. In half of these both methods mentioned were run together—i. e. the method of total gas-volume measurements, and the method of percentage determinations of the oxygen, gasoline-vapor, etc., present at the start and the end of each separate test in the series. The cautionary checks were also observed. Four series of tests were run to determine the influence of chloroform-vapor upon the rate of oxygen transfer through lecithin membranes. These four series of tests were carried out by the one method only—namely, that of the total gas-volume measurements at the beginning and end of each test.

The results of all the experiments by both methods pointed directly to the conclusion that, in the presence of gasoline-vapor air or chloroform-vapor air, the membranes named permitted less oxygen to pass per unit of time than they permitted in air only.

Note that the experiments with the covered preparation dish of lime-sulphur were carried out under the conditions encountered regularly by the tissue cells of an insect subjected to fumigation by gasoline-vapor or chloroform-vapor. Just as oxygen reached the lime-sulphur for absorption at a lower rate, when passing through the lecithin membrane in the presence of gasoline-vapor or chloroform-vapor, so, it may be judged, less oxygen would be able to reach the oxygen-absorbing protoplasm of the cells through the surrounding body fluids (blood) etc., the lipoids of which held gasoline-vapor. So also, in the presence of air containing that vapor, less oxygen would be able to pass through the surface of an insect-tissue extract (containing hydroquinone, for example) into the extract where it could be utilized by the oxidase in oxidizing hydroquinone.

Now, the actual percentage of oxygen present in the gasoline-vapor air would naturally be lower than in normal, pure air through dilution by the gasoline-vapor, but it appeared that this alone could not fully account for the lower rate of oxygen transfer through the membranes. Attention may be called to the fact that when the percentage of oxygen in the air of the container, for the "air only" tests, was made as nearly equal as possible to the percentage of oxygen in the gasoline air used (see Nos. 3 and 4, Table VII), the rate of oxygen transfer through the membrane remained lower, nevertheless, in the presence of gasoline-vapor. In Exp. 3 (Table VII) the oxygen percentage was 20.2 at the beginning, and 18.26 at the end of test No. 1. In test No. 2, carried out in "gasoline-vapor air" mixture, 18.26 per cent oxygen was present at the start and 17.5 per cent, at the end. Test No. 3 of Exp. 3 was started after the covered preparation dish had been aired several hours. All the gasoline had not been given up by the membrane, however—and by the end of the test, the small percentage of gasoline-vapor shown in the table had been given off to the air of the container. A very thick lecithin-lard membrane had been used. In Exp. 4 (test No. 1) of the same table, the percentage of oxygen at the beginning was 15.13, and at the end, 13.2. In test No. 2 of this experiment, the gasoline-vapor air contained 14.6 per cent oxygen at the start, and 13.11 per cent at the end. The conclusion in regard to this point must be, therefore, that the gasoline-vapor which was taken up by the membranes rendered them less permeable to oxygen. Representative results are given in Table VII.

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TABLE VII.—SHOWING THE INFLUENCE OF GASOLINE-VAPOR, CHLOROFORM-VAPOR AND LIME-SULPHUR SOLUTION UPON THE PASSAGE OF $O_2$ THROUGH CERTAIN SPECIFIED MEMBRANES.

| Exp. No. | Test No. | Membrane cover used. | Insecticide-vapor used. | Per cent of Insecticide-vapor at end of test. | Temp. Cent. | Total time exp. ran. | Total $O_2$ absorbed. | $O_2$ absorbed, or $O_2$ passing through membrane per period of 10 hrs. | Excess of $O_2$ passing through membrance per 10 hr. period in pure air over that in insecticide-vapor-air mixture. |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 1. | Lecithin | Air only | | 23.2° C. to 22.6° C. | 2¼ hrs. | 3.8 c. c. | 13.8 c. c. } Average | |
| | 2. | Lecithin | Air only | | 23.3° C. | 1 hr. | 1.5 c. c. | 15.0 c. c. } 14.4 c. c. | 10.4 c. c. |
| | 3. | Lecithin | Gasoline vapor | 2.8% | 24.2° to 21.4° | 15 hrs. | 6.1 c. c. | 4.0 c. c. | |
| | 4. | Lecithin | Gasoline vapor | 3.5% | 21.4° to 20.4° | 3¼ hrs. | 2.42 c. c. | 7.6 c. c. | 6.8 c. c. |
| | 5. | No cover | Gasoline vapor | 4.4% | 26.0° to 25.6° | 3½ hrs. | 3.8 c. c. | 10.8 c. c. | |
| | 6. | No cover | Gasoline vapor | 4.4% | 25.6° | ¾ hrs. | 0.8 c. c. | 10.6 c. c. | |
| 2. | 1. | Lecithin | Air only | | 25.6° to 27.4° | 1¼ hrs. | 1.6 c. c. | 9.6 c. c. | |
| | 2. | Lecithin | Gasoline vapor | 2.7% | 24.8° to 25.4° | 3 hrs. | 1.47 c. c. | 4.9 c. c. | 4.7 c. c. |
| | 3. | No cover | Gasoline vapor | 3.7% | 28.2° to 27.4° | 2 hrs. | 1.6 c. c. | 8.0 c. c. | |
| 3. | 1. | A thick Lecithin—lard cover | Air only | | 25.2° to 24.4° | 24 hrs. | 2.4 c. c. | 1.0 c. c. | 0.809 c. c. |
| | 2. | A thick Lecithin—lard cover | Gasoline vapor | 5.37% | 25.0° to 27.2° | 24 hrs. | 0.46 c. c. | 0.191 c. c. | |
| | 3. | A thick Lecithin—lard cover | Air (gasoline vapor) | 0.55% | 27.2° to 24.0° | 24 hrs. | 1.17 c. c. | 0.48 c. c. | 0.52 c. c. |
| | 4. | No cover | Gasoline vapor | 5.7% | 22.4° to 21.4° | 4 hrs. | 2.07 c. c. | 5.17 c. c. | |
| 4. | 1. | Lecithin—lard | Air only | | 25.0° | 6 hrs. | 3.5 c. c. | 5.83 c. c. | 3.45 c. c. |
| | 2. | Lecithin—lard | Gasoline vapor | 4.54% | 26.6° | 6 hrs. | 1.43 c. c. | 2.38 c. c. | |
| | 3. | Lecithin—lard | Air again | | 27.2° to 26.6° | 6 hrs. | 2.05 c. c. | 3.4 c. c. | |
| | 4. | No cover | Gasoline vapor | 5.1% | 22.8° to 22.0° | 4 hrs. | 1.98 c. c. | 4.95 c. c. | |
| 5. | 1. | No cover | Air only | | 24.2° | 4-5 hr. | 1.8 c. c. | 22.5 c. c. | |
| | 2. | No cover | Chloroform vapor | | 25.4° | 1½ hr. | 1.5 c. c. | 10.0 c. c. | |
| | 3. | Lecithin | Chloroform vapor | | 25.0° | 1 hr. | 0.5 c. c. | 5.0 c. c. | 11.0 c. c. |
| | 4. | Lecithin | Air only | | 25.2° | 1 hr. | 1.6 c. c. | 16.0 c. c. | |
| | 5. | No cover | Air only | | 25.0° | 2 hrs. | 3.7 c. c. | 18.5 c. c. | |
| 6. | 1. | No cover | Air only | | 20.0° | 1 11-12 hrs. | 2.3 c. c. | 12.0 c. c. | |
| | 2. | Lecithin | Air only | | 20.0° | 2 hrs. | 2.0 c. c. | 10.0 c. c. | 4.0 c. c. |
| | 3. | Lecithin | Chloroform vapor | | 21.0° to 21.4° | 1 hr. | 0.6 c. c. | 6.0 c. c. | |
| | 4. | No cover | Chloroform vapor | | 19.8° to 20.0° | 1½ hrs. | 1.5 c. c. | 11.2 c. c. | |
| 7. | 1. | Bees wax membrane | Air only | | 27.0° | ¾ hr. | 1.2 c. c. | 18.0 c. c. | |
| | 2. | Bees wax membrance wet with lime-sulphur solution | Air only | | 25.2° | 48 hrs. | 18.46 c. c. | 3.8 c. c. | 14.2 c. c. |
| | 3. | No cover | Air | | 25.2° | 1 hr. | 1.2 c. c. | 12.0 c. c. | |
| 8. | 1. | Shellac | Air | | 26.0° | 1 hr. | 1.4 c. c. | 14.0 c. c. | |
| | 2. | Shellac wet with lime-sulphur | Air | | 25.6° to 25.4° | 2¾ hrs. | 1.6 c. c. | 6.0 c. c. | 14.0—6=8.0 c. c. |
| | 3. | Shellac wet with lime-sulphur | Air | | 25° | 7-12 hrs. | 0.1 c. c. | 1.7 c. c. | 14.0—1.7=12.3 c. c. |
| | 4. | Shellac wet with lime-sulphur | Air | | 25.0° to 24.8° | 50 hrs. | 1.1 c. c. | 0.22 c. c. | 14—0.22=13.78 c. c. |
| | 5. | No cover at end | Air | | 24.8° to 25.0° | 1 hr. | 1.7 c. c. | 17.0 c. c. | |

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Before figuring the rates given in Table VII, all gas-volumes were reduced to 0° C, and 760 m. m. mercury pressure. Since all tests were not run for equal periods of time, it was necessary to figure results to some certain period—a ten-hour period was used. Results of experiments with gasoline-vapor are those obtained through estimating the actual amount of oxygen present at the beginning and end of each test. Where two or three determinations were made, the value given under any test number in the table is the value which came nearest the average. As has already been mentioned, however, all determinations (by both methods) led to the same general conclusion already stated.

In this connection, it occurred to the author that a good opportunity had presented itself for testing the effect of lime-sulphur, itself, upon the permeability of a wax membrane to oxygen. Accordingly two series of tests, results of which are given under Nos. 7 and 8 of Table VII, were carried out, using bees wax and shellac membranes. The membranes were formed by dipping thin India linen in melted beeswax, and in melted shellac, until membranes of the desired thickness were obtained. After the tests with a dry membrane had been carried out, the preparation dish (over which the membrane was fastened as a cover) was inverted and shaken until the lime-sulphur in the dish had thoroughly wet the surface of the membrane inside the dish. Before test No. 2 of Exp. 8 was tried, the preparation dish was only shaken. It was again thoroughly shaken, before test No. 3; and before the fourth test the dish was inverted—the lime-sulphur solution being left in contact with the shellac membrane, thus, for 25 minutes. In that time, the solution had "taken hold" and thoroughly wet the membrane. Note the decline in the rate of oxygen transfer. Both sets of tests showed that much less oxygen was absorbed (i. e. passed through the membrane) after the membrane-surface, inside the preparation dish, had been wet with the solution. That is, the lime-sulphur solution rendered the wax membranes decidedly less permeable to oxygen—less able to transmit oxygen. There seems to be no reason why lime-sulphur* would not have the same effect upon the wax covering of a scale insect, such as that of the *San Jose* scale.

A few experiments had been made a long while ago with living grasshoppers (*Melanoplus*) in air containing very strong fumes of osmic acid. These insects were darkened, and were rendered clumsy in their movements, but they lived for many hours in the fumes of the acid. It seemed a wonder that they could thus withstand the fumes—and that the fumes did not penetrate. In addition to the membrane-experiments just recited, therefore, one set of tests was carried out to determine the rate at which oxygen from air could pass through a lecithin-lard membrane before and after the membrane had been exposed to strong osmic acid fumes. Oxygen passed through the membrane at the rate of 1.3 c. c. per hour before treatment with the fumes. The membrane was treated (from one side) with the fumes for over three hours. It was then aired over night, and on the next day, in the three tests made, the darkened membrane did not transmit oxygen at a greater rate than 0.2 c. c. per hour—i. e. the rate was about six times slower than before the treatment. The lecithin-lard membrane was penetrated by the fumes but slowly.

*Some other scalecide properties of lime-sulphur are given in Tech. Bull. 11.

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(The very poor penetrating power of osmic acid fumes, when used as a histological killing agent, are well known.) It may only be suggested here that perhaps the first effect of osmic acid fumes in blackening lipoids and fats in the experiment-membrane (or the surface of a living grasshopper, etc.) is to establish a black surface-membrane at once which is not only a little less permeable to oxygen, but also much less permeable to the osmic acid fumes, themselves.

## THE EFFECT OF TEMPERATURE ON THE CAPACITY OF LIVING INSECT TISSUES FOR THE ABSORPTION OF CERTAIN GASES OR VAPORS.

In Table VI results are given of gasoline-vapor absorptions by 3-gram samples of egg-albumen, and also by the same amounts, respectively, of fresh unincubated egg-yolk and of fertile egg-yolk after four and five days of incubation. It was a surprise, in these tests, to find that gasoline vapor was about six times more soluble in egg-albumen than in the fresh egg-yolk, although the latter contained fats and fat-like material in the greater amounts by far. All other tests, so far carried out, had shown fats and lecithin to have greater capacity for the absorption of gasoline-vapor than egg-albumen. The exception, therefore, seemed so interesting and so possibly significant that it was decided to test the absorption capacity of the yolk for gasoline-vapor after certain periods of incubation. The yolk of infertile eggs, even after several days of incubation, was found to give the same results as yolk taken from fresh unincubated eggs. In the case of incubated fertile eggs the young, developing embryo was stirred up with the yolk before the 3-gram sample for the absorption test was taken. A comparison of such results of yolk-absorptions as are given in Nos. 2 and 3 with those given in Nos. 5 and 6 of Table VI seemed to show that the solubility, for gasoline-vapor, of fats and lipoids in the yolk changed greatly in the four and five days of incubation. The first few hours of incubation did not bring about a measurable change in the capacity of the yolk to dissolve gasoline-vapor. All the tests with yolk samples as given in the table were made at a room temperature of 25° to 26° C. Four tests with yolk samples of only a few hours incubation were made in a small incubation room at 103° F. These gave practically the same results, as to absorption capacity, as similar tests at the ordinary room temperature; if there was any increase in that capacity, it was not great enough to measure. As is well known, on about the fourth and fifth days of incubation the embryo of the hen's egg begins to show quite decided respiratory activity, and a period of rapid development begins. It was at this period of incubation that the decided increase in the capacity for absorbing gasoline vapor was shown by the embryo-yolk-mixture.* Here was an interesting change, (an increase) in the absorption capacity of the yolk-mixture for gasoline vapor, which seemed to be related with the changes that made for active development in the embryo. As long as the embryo remained comparatively dormant (or, was unable to develop through non-fertilization,

*Attention should be called to the fact that absorption results in 5 and 6 are much greater than the absorptions given by egg-albumen (i. e. egg-white). It would seem that the change in the embryo-yolk-mixture, which occasioned an increase in the gasoline-vapor absorptions, was probably a change in the fats and lipoids. The amount of alcohol-soluble material in the embryo is said to increase rapidly with development.

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when incubated) the capacity for absorbing gasoline vapor remained comparatively low. These facts surely seemed significant in connection with the behavior of gasoline vapor, and the like, toward dormant insects.

It is a well known rule that dormant insects are harder to kill with fumigants (such as gasoline vapor, carbon disulphide, etc.), and that they are more resistant to sprays of kerosene emulsion and the miscible oils in general than are active insects of the same species. The question naturally arose in this connection, therefore, as to whether insects in the dormant state, from cold say, might not absorb less gasoline vapor under a given fumigation charge than they would absorb when in the active condition. In view of the close relation which the question bore to the main problem of how contact insecticides kill, experiments were planned to determine whether dormant insects would take up less of such a fumigant as gasoline vapor than would be taken up by the same insects after they had been brought into an active condition.

Hibernating Luna moth pupae were selected as the first insects to be used in these experiments, and gasoline vapor was the fumigant chosen. This fumigant was used again in this case for the reason, already mentioned several times, that it permitted of accurate percentage determinations of itself and of the oxygen and carbon dioxide present in the air in which it was used. The pupae had been kept in the cold room of the insectary all fall and winter until the experiments were first undertaken December 17, 1913. The apparatus represented in Figure III (except for the hooked U-tube, and the burette "f") was moved into the cold room six to eight hours before an experiment was to be begun, in order that everything might reach the temperature of that room. Among the accessories was a separate gas container with a stock supply of gasoline-vapor-air, and a little water to maintain saturation with water vapor. The dormant pupae were floated up on mercury in the gas container "c", Fig. III. The mercury in the container was raised until almost all air was expelled and the pupae were near the top. The outlet cock "t" of the container "c" was then connected with the stock-container of gasoline-vapor-air and the required amount of gasoline-vapor-air was quickly drawn in with the pupae. Within the next half minute, a sample of the gasoline-vapor-air with the pupae was drawn off above mercury into a separate gas-container, to be kept for percentage estimations. The mercury manometer, "m" Fig. III, was quickly leveled and the apparatus was then watched until the first rapid loss in volume had passed, and the manometer showed that no more gasoline vapor was being absorbed. Then, a second sample of the gasoline-vapor-air confined with the insects was drawn off for estimation in the same manner as the first. Both the samples (one taken at the beginning and one at the end of the test) were removed to the laboratory and allowed to stand until they reached the temperature of the room and of the apparatus (i. e. gas-pipettes and compensation burette;* (see Fig. 4, p. 27, Tech. Bull. 11, this station) used in making the percentage estimations. After that, the percentages of gasoline vapor, of carbon dioxide, and of oxygen present at the beginning and at the end of the absorption test with the pupae were determined. From these results, knowing the volume of gas present with

*By means of this burette, direct volume measurements at 0°C. and 760 m. m. mercury pressure, with proper water vapor-tension corrections, could be made.

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the insects at the beginning, the amount of gasoline vapor present at the start, and the amount absorbed, could be figured.

At the end of the absorption test, the pupæ were carefully removed from the container and aired. They were then brought into the laboratory, where they might warm up and start active development. After their actions, taken in connection with respiration tests, showed that they were in an "active state", an absorption test with gasoline-vapor-air (using as nearly as possible the same percentage and the same amount of gasoline vapor) was carried out in the warm room by the same method as in the former case.

Two separate experiments with Luna moth pupae, entailing the complete sets of estimations just outlined, were carried out by this method. Results of these two experiments are given in Table VIII, Nos. 1 and 2.

TABLE VIII.—INSECTICIDE-VAPOR ABSORPTIONS OF COLD (DORMANT) AND WARM (ACTIVE) INSECTS.

| Exp. No. | Insects. | Vapor used. | Temperature. | Volume of vapor absorbed. | Time. |
|---|---|---|---|---|---|
| 1. | 6 Pupae of Luna moth; 15 grms... | Gasoline vapor 2.6%..... | 9.2° C..... | 0.38 c. c..... | 2 hrs. |
| | 6 Pupae of Luna moth; 15 grms... | 2.8%..... | 24.6° C..... | 1.13 c. c..... | 2 hrs. |
| 2. | 9 Pupae of Luna moth; 20 grms... | Gasoline vapor 2.12%..... | 7.2° C..... | 0.35 c. c..... | 1 hr. |
| | 9 Pupae of Luna moth; 20 grms... | 2.4%..... | 24.8° C..... | 0.89 c. c..... | 1 hr. |
| 3. | 5 Passalus cornutus, 10 grms..... | Ether..... | 0.6° C..... | 1.2 c. c..... | 10 min. |
| | 5 Passalus cornutus, 10 grms..... | Ether..... | 0.6° C..... | 1.4 c. c..... | 30 min. |
| | 5 Passalus cornutus, 10 grms..... | Ether..... | 22.2° C..... | 6.0 c. c..... | 10 min. |
| | 5 Passalus cornutus, 10 grms..... | Ether..... | 22.2° C..... | 7.5 c. c..... | 30 min. |
| 4. | 5 Passalus cornutus, 11.2 grms.... | Ether..... | −1.0° C..... | 2.40 c. c..... | 10 min. |
| | 5 Passalus cornutus, 11.2 grms.... | Ether..... | −1.0° C..... | 2.45 c. c..... | 15 min. |
| | 5 Passalus cornutus, 11.2 grms.... | Ether..... | 23.4° C..... | 5.2 c. c..... | 10 min. |
| | 5 Passalus cornutus, 11.2 grms.... | Ether..... | 23.4° C..... | 5.4 c. c..... | 15 min. |
| 5. | 5 Passalus cornutus, 10.5 grms.... | Ether..... | −2.0° C..... | 0.7 c. c..... | 10 min. |
| | 5 Passalus cornutus, 10.5 grms.... | Ether..... | −2.0° C..... | 0.8 c. c..... | 20 min. |
| | 5 Passalus cornutus, 10.5 grms.... | Ether..... | 24.0° C..... | 5.1 c. c..... | 10 min. |
| | 5 Passalus cornutus, 10.5 grms.... | Ether..... | 24.0° C..... | 6.0 c. c..... | 20 min. |
| 6. | 5 Passalus cornutus, 10 grms..... | Ether..... | −2.4° C..... | 0.4 c. c..... | 10 min. |
| | 5 Passalus cornutus, 10 grms..... | Ether..... | −2.4° C..... | 0.5 c. c..... | 20 min. |
| | 5 Passalus cornutus, 10 grms..... | Ether..... | About 20.0° C. | 1.2 c. c..... | 10 min. |
| | 5 Passalus cornutus, 10 grms..... | Ether..... | About 20.0° C. | 1.5 c. c..... | 20 min. |

At the beginning of Exp. No. 1, in the cold room, there were 2.08 c. c. of gasoline vapor present in the air with the pupæ. The table shows that 0.38 c. c. of the vapor was absorbed—that is, only 0.18 of all the gasoline vapor present at the start was absorbed by the six pupae. The latter were all alive when brought into the warm room. They were kept in moist air and their activity increased. By the third day, the respiration had increased to more than three times its rate in the cold room. On the sixth day, the rate was about the same or slightly less. The pupae were kept in the warm room 17 days, in all, before the last absorption test was made. Since, by the method used, not all the air was expelled from the container before gasoline-air was drawn in with the pupae above the mercury, it was impossible to make sure that the percentage of gasoline vapor used in the warm room was *just* the same as was used in the cold room test. As may be seen by the table, however, it was possible to make the percentages *almost* or *practically* the same. In the warm room test of Exp. 1, there were 2.24 c. c. of gasoline vapor present in the air used, and 0.5+ of all this was absorbed by the same

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pupae which in the dormant stage had absorbed only 0.18 + of the 2.08 c. c. of gasoline vapor placed with the air used in the cold room test.

When the nine pupae, used in Exp. 2, were removed from the gasoline-vapor-air at the end of the test in the cold room, they had become quite sensitive to touch. They would wriggle actively when touched. The gasoline vapor seemed to have stimulated them. They were removed to the warm room and kept there about 15 days before the second absorption test was run. In this experiment 1.96 c. c. of gasoline vapor was present in the air at the beginning of the warm room test, and 0.45+ of this vapor was absorbed by the pupae as against only 0.2 + of the 1.7 c. c. of vapor present in the air during the cold room test. About 80 c. c. of gasoline-vapor-air was present at the end of each test. The ratio of the *absorbed* gasoline vapor to the whole amount present was, in both experiments, greatest in the warm room tests where the insects were undergoing active development. All the pupae recovered at the end of the tests, and the first moths began to emerge about five days after the last tests in each experiment. Adults emerged from all the pupae, although none were very perfect moths. After the above experiments, it was decided to use adult *Passalus cornutus* in absorption-tests made, first, when the beetles were quiet and dormant from cold, and again when they had become active in the warm room. These beetles were chosen because, as has been explained in Bulletin 11, all of the air could be safely forced out from around these insects by mercury. Thus, it was possible to introduce samples of the *same* stock of insecticide-vapor-air into the container, unmixed with other air, in the cold room and in the warm room. Air that was almost, but not quite, saturated with the insecticide vapor at the cold room temperature was kept in a gas container above mercury as the stock-supply. One could, in this way, be sure that the percentage of insecticide vapor present, in both tests, was exactly the same. With this assurance that the same percentage of the insecticide vapor could be placed with the insects in the two different tests, it was not necessary to use a vapor which would permit of accurate quantitative estimations of the percentage present at the beginning and end of each test. Thus, different apparatus and a different method might be employed. The method of measuring the total rapid decrease in volume could be depended upon, it appeared, to show the volume of insecticide vapor absorbed by the insects. Experience had shown that most of the vapor-absorption would take place in an interval too short for respiration to make an appreciable change in volume. Moreover, in the short interval necessary, barometer and therometer readings remained practically the same. The apparatus used for making the gas measurements was the compensation-burette just referred to (Shown in Fig. 4, Tech. Bull. 11, and a gas-container of the type shown at A., Fig. 7, Tech. Bull. 11 of this station.

A certain measure of the insecticide vapor to be used was transferred from the stock supply into the compensation burette. The beetles were floated, dorsal side up, on mercury in a gas-container, and the mercury was raised until all air was expelled from around them. The container was at once connected with the compensation gas-burette, and the accurately measured sample of insecticide vapor was quickly drawn over

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with the beetles. After 10 minutes the whole remaining volume was returned to the compensation-burette and again accurately measured. The first reading minus the second reading of the compensation burette showed the amount of vapor that had been absorbed by the insects. The gas could thus be transferred back and forth at intervals to obtain absorption values at 10, 20 and 30 minute intervals, if desired. At the end of this test in the cold room, the beetles were removed to fresh air; and after an hour or two were brought into the warm room along with the apparatus and the stock supply of insecticide vapor. After 18 to 41 hours, when the beetles had become active and everything to be used had reached the room temperature, absorption-tests were again carried out with the same insects—using a sample of the same insecticide vapor under the new conditions. Now, gasoline did not produce a very high percentage of vapor at the cold room temperature; and a fluid which would give a higher percentage of vapor at the low temperature seemed desirable. On that account, ether was selected for the new trials instead of gasoline.

Four experiments were carried out in the manner just outlined, using *P. cornutus*, and the vapor of ether in air. The results of all four of the experiments are given in Table VIII. In no case, as may be seen, were the absorptions less than two times greater in the warm room, where the beetles were active, than when the latter were dormant in the cold room. In experiments 3, 4 and 5, in the cold room, the small amount of absorbed ether-vapor stimulated the dormant insects until they twitched the antennae and moved the legs. On the other hand, in the warm room tests of Exp. 3, the active beetles had become entirely motionless (anaesthetized) in 10 minutes; at the end of Exp. 4, only a bare movement of the antennae could be noticed, still; and in the warm room test of Exp. 5, the active beetles were completely anaesthetized by the end of 20 minutes. In the case of Exp. 6, the beetles were entirely stiff and helpless at minus 2.4° C., and they remained so even under the influence of the small amount of ether absorbed. When these insects were removed from the first test, they showed no movement whatever; and they recovered from the cold, only slowly, after being brought into the warm room. They had been kept in the cold (at minus 2.4° C.) only a few hours in all. A different stock supply of ether-vapor-air was used in Exp. 6, and the five beetles absorbed only 1.5 c. c. of the vapor even in the warm room in 20 minutes. This was barely enough of the ether to place the insects in the excitement state—they were more active at the end than at the beginning of the last test.

In order to show how nearly constant a certain volume of pure air remained during a period of 30 minutes with five beetles, a single check may be related. The five beetles used weighed 10 grams. The 50 c. c. of pure air was transferred from the compensation burette to the container with the beetles and back again three times during the check, with the following results:

50.0 c. c. at the beginning;
50.2 c. c. at end of 10 min. (after first transfer);
50.0 c. c. at end of 20 min. (after second transfer);
49.9 c. c. at end of 30 min. (after third transfer).

The six experiments (Table VIII) were carried out with such care,

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and were checked in such a manner, it is believed, as to make the apparent conclusion seem undoubted. In the dormant condition, the insects absorbed less gasoline vapor and less of the vapor of ether than did the same insects when active. The difference in solubility of the insecticide vapors in the dormant and in the active insects, was so great that ordinary charges of the insecticides used did not bring the concentration of the insecticide, within the body tissue of the dormant insects, to the danger point. Thus, the lowered absorption capacity, which accompanied the dormant condition, may easily furnish the chief explanation of the fact that insects, dormant from cold, are harder to kill by ordinary fumigants and by ordinary miscible oil, contact sprays.

Evidence has been given that the tissue fats and lipoids of living insects should be considered as the principal solvents of such insecticides as gasoline and kerosene vapors, ether and the like. The suggestion made in connection with egg-yolk absorptions, therefore, seems proper here. Namely, the changes, which accompanied respectively an active or a dormant state, occasioning an increase or decrease in the capacity for absorption of insecticide vapors, was probably a change in the condition of the tissue fats and lipoids—or, in their relation to the other cell constituents..

## IN REGARD TO THE MANNER IN WHICH BORAX AND SOME OTHER POWDERS (SOLID CONTACT INSECTICIDES) BECOME EFFECTIVE AGAINST CERTAIN INSECTS.

Mention has already been made (Technical Bulletin 11) of certain dry powdered solids that may be applied as contact insecticides. In the case of pyrethrum powder, attention was called to the fact that, as applied in most cases, the principal influence of this insecticide is due to the volatile bodies held in the powder. This is very clear when the insect is confined in a warm air-space with some of the powder. However, certain insects (for example diptera and grasshoppers) may sometimes be overcome—for a time, at least—by dusting their bodies with the powder, even in the open air. When such insects are examined, one may often observe with a binocular microscope that some of the powder becomes lodged in the dry vestibule of the tracheæ within the spiracles, and no doubt the volatile bodies from the powder charge the air in the tracheal system. The poison in such cases, therefore, really becomes absorbed as a gas or vapor. Nevertheless, it is possible in the case of some insects for certain dry non-volatile powders to become effective as contact insecticides. White hellebore (although it contains a slightly volatile body) does not kill insects confined in the air with it at ordinary temperatures, provided they do not come in contact with the poison—or do not eat it. It is well known that the fresh hellebore powder is a stomach poison to insects; it may be observed to be effective as a contact insecticide also, with moist rose slugs. I have watched many young rose slugs that did not *attempt* to eat after their bodies had been powdered with fresh hellebore. If they attempted to crawl, the body seemed to be clumsy as if the hypodermal sense organs had been numbed; and usually, the slugs would fall from the leaf. Slugs, in this condition, were kept for varying lengths of time (up to nearly two days) until they died.



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It was clear that the body secretions had dissolved some of the hellebore, and had moistened more of it so that it stuck as a white crust on the body. The indications were that but very little of the hellebore, dissolved in the body secretions, had been absorbed through the cuticular covering—only enough to render the outer surface of the body numb and clumsy. In the final stages, the insect seemed to be dying, more from drying and from starvation than anything else—yet it was the hellebore which first rendered the animal in an unfit condition for normal life-processes.

Borax powder and finely powdered sodium fluoride have been used as effective agents against cockroaches. It was known to be not at all necessary to place these powders on a bait that should be eaten by the roaches; the dry powders became effective if they were dusted in locations where the insects were sure to run. There seemed to be nothing appetizing about the powders, in themselves, and it was a question *how* they became effective against roaches. The large American cockroach (*Periplaneta Americana*) and the smaller croton bug were available for study in this connection.

In the first tests, a little dry powder of borax, or of sodium fluoride was sprinkled on one-half the bottom of wide, flat, glass-covered culture dishes. Then single roaches were introduced and watched. It was soon noticed that when a roach ran through either the borax or the sodium fluoride, a little of the dry powder stuck to the lower part of the body and to the legs—especially at the bases of the legs, and between the sternal plates. Also, the insect was almost sure to get its antennae dusted with the powder as it waved them about. If left to itself, a roach that had become powdered in the manner just described would soon settle down and begin "cleaning up." In this latter process, the long antennae were drawn across the mouth and licked clean—the feet and legs and body were licked. After a time, a roach that had been cleaning itself of either of the powders named would begin to show uneasiness and irritability. It was apt to become sick, after a time, and exude a drop of saliva from the mouth. Finally, the insect would become dumpy, often remaining quiet for long intervals, only to start up suddenly and nervously, and then lapse again. Such actions were usually followed by partial paralysis of the hind and middle legs. The wings and feet twitched at intervals, and gradually the body became more helpless until death resulted. This might all take place in anywhere from four to forty-eight hours; and the length of time before death would result seemed to depend in great part upon the amount of powder the roach had cleaned from his body. As a rule, the sodium fluoride acted very much more rapidly than the borax—requiring only four to twelve hours. Sometimes a roach that had taken only a little borax, in cleaning the powder from its body, would pass through the first stages of uneasiness (and apparent stomach-sickness) and then recover so far as to eat, and act normal for four or five days, perhaps—after which it would become dumpy. It would then eat no more. The wings would quiver when the insect was disturbed; paralysis of the legs would finally set in, and gradually the body would become more helpless in every case until death resulted.

Observations were made, and record was kept (from treatment to

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death) of the actions of 45 of the insects treated with borax, sodium fluoride, or borax and pyrethrum mixed. A few tests were made by compulsory feeding of the roaches with a very little borax or sodium fluoride from the point of a small knife-blade. In every case the symptoms were much like those described above and the insects finally died. These last tests made it clear, therefore, that both borax and sodium fluoride could act as stomach poisons in the case of the cockroach. Moreover, it seemed very likely that in cleaning either of the powdered poisons from antennae, feet and body, the insect would eat enough of the poison to kill. Finally, visible proof was obtained that powder, licked from various parts of the body, was swallowed. Sodium carmine was very thoroughly dried and pulverized with borax, and with sodium fluoride. Insects were placed with this stained powder, and several hours after they had cleaned it from their bodies, dissections were made; the red stain was found in the contents of the crop.

The question still remained, however, as to whether a little of the powdered insecticides might not be dissolved in the moist exudations at the bases of the legs and between the sternal plates, and then absorbed through the thinner body integument in the locations named. It seemed possible also that the very fine powder might enter the spiracles. That is, it was still a question as to whether the powders under consideration might not be contact insecticides as well as stomach poisons when used against roaches. In order to get at the solution of this question, it was found to be absolutely necessary to devise some way of preventing the insects from licking their bodies after they had become dusted with the powder—without, at the same time, inflicting any serious mechanical injury in the use of the preventative device. The desired result was accomplished by means of card board collars, which were prepared and used in the following manner:

The collars were made from single pieces of flat bristle board of about the weight of ordinary medium index cards. Each collar was four to four and one-half inches in diameter—i. e. large enough to form a cover over a shallow glass stender dish. A slit was cut in the circular card from the circumference to the center, where a small smooth hole was punched. This central opening was large enough to turn freely on the neck of a cockroach, but it was very much smaller than the animal's head. After the collar had been very carefully placed around the neck of a roach, a thin strip of paper was afterward pasted over the slit. The flat collar could then be placed over the stender dish, containing a little powder to be tested, so that the insect's body rested upon the bottom of the dish, and the head stuck up above the collar outside the dish. The fluttering wings and scrambling legs would thoroughly dust the animal's body without any of the powder's reaching the head or mouth. Fig. No. 4 of Plate I shows the position of the head of a cockroach wearing such a collar. In check tests, untreated roaches were made to wear collars for eight, eighteen, and even ninety-eight hours without any serious injury. After these specimens were released, they were kept under observation for ten to nineteen days, and during that time fed and behaved normally. In all these experiments the roaches were permitted to have moist food when no insecticide powder was present and they were not wearing a collar.

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In order to be able to see just where the powder went, when it came in contact with the body of an insect wearing a collar, both borax and sodium fluoride were stained with either sodium carmine, or indigo carmine, after which they were thoroughly dried and pulverized to a powder. In a few cases, where dissections were to be made under water, Sudan III was used as the stain for the insecticide powder. Individual experiments were carried out with more than forty insects according to the outline just given, and all these were in agreement as to the question considered. It was found that powdered borax and powdered sodium fluoride could bring about the death of roaches through being dusted thoroughly on their bodies, without ever having come in contact with the mouth. The dusting of the body was done through the efforts of the insect itself, in scrambling and fluttering with the legs and wings in the manner already explained. Borax required two to ten days to cause death through contact of the powder alone. Sodium fluoride required from five to twenty-two hours. In each case the average time was much longer than was required to bring about death when the insect had eaten some of the powder in cleaning the same from its body. The symptoms following contact alone were usually very similar to those which followed when the poison had been eaten. As a rule, the period of partial paralysis and helplessness was much more prolonged when the powder had been used only as a contact insecticide. The exudation which caused the powder to stick to the roach's body was nearly always sufficient to dissolve enough of the borax or sodium fluoride to cause incrustation at the bases of the legs, between the sternal plates, etc.

In seventeen of the experiments in which the stained insecticide powder (sodium carmine was the stain mostly used) had been employed, the insects were dropped into a hot alcoholic fixing fluid at about the time of death. Afterward, parts of the bodies of these insects were embedded, and sectioned. A study was made of the miscroscopic sections prepared in this way, in order to learn by means of the stain if possible, whether the powder had entered the spiracles—or had passed, after solution, into the insect's body through the thinner portions of the body wall. The sections showed the incrustations of the stain at the bases of the legs, between the sternal plates, and (sometimes) just within the spiracles in the vestibule from which the tracheae arise; but no stain was found further within the tracheæ, and no sections were found which showed undoubted evidence that the stain had penetrated the integument to stain the hypodermal cells. If the cuticula was permeable to the stain and to the borax or sodium fluoride solutions in the same degree, then it is certain that only a very limited amount of the insecticide passed into the animal's body through the thinner portions of the body integument. The latter, however, seems to have been the possible and probable path. No indication was found that the stained insecticide powder had entered the bodies of cockroaches wearing the collars, in any other way. It must be remembered that the sodium fluoride rendered roaches helpless and practically dead in some cases within five hours—i. e., during the time the insects were wearing the collars, and sections showed no trace of stain in the crops of these insects. It took the borax so long to kill by contact that in the first tests, the roaches were brushed as clean as possible after six to eight hours treatment, and were then re-

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leased from the collars. Proof was soon obtained that this would not do; the insects licked the joints of their legs and other rough parts of the body so thoroughly that the contents of the crop became decidedly stained. In other words, the insects did their cleaning so carefully that they might be eating enough of the borax powder to kill. The only safe method, therefore, was to leave the collars on the animals until they were no longer *able* to lick various parts of the body. That the death of an insect so treated was due primarily to the influence of borax powder brought in *contact* with the body, and not to injury from the collar (or otherwise) was shown by the checks carried out with untreated insects in collars, and by the absence of any stain in the digestive tract.

The evidence gained from the experiments carried out in this connection, therefore, may be summed up in the following statements:

When cockroaches run through powdered borax, sodium fluoride, or borax and pyrethrum mixed, the dry powder sticks to the legs, body, and often to the antennae. Some of the powder is moistened or dissolved in the exudation about the bases of the legs and on the thinner portions of the outer integument. This seems to cause some irritation and uneasiness; the insect soon begins to clean the moistened powder from the body by licking it. In doing this, enough of the poison may be brought into the mouth, and swallowed, to kill after a period varying from five hours to ten days. Borax acts much more slowly but kills with no less certainty than sodium fluoride. It is possible for both powdered borax and sodium fluoride to kill roaches by contact (without any of the poison's having been swallowed), but in actual practice it is hardly possible that any roach ever gets its body dusted with one of these powders without also licking and swallowing some of the powdered poison. Both powders are more rapid in their action as stomach poisons than they are as contact insecticides.

Tables IV and V contain representative results illustrating the influence of borax, sodium fluoride, pyrethrum and white hellebore on the reductases and catalases, respectively, of insect extract. Borax acted quite injuriously on the activity of the reductase, and very little on that of the catalase. The same was true of the hellebore and pyrethrum, except that the pyrethrum seemed to interfere a little more with the activity of the catalase than did either the borax or the hellebore. Sodium fluoride was most detrimental to the catalase. When added to perfectly fresh extract, the sodium fluoride caused a slight drop in reductase activity; after that however, such a treated extract retained its reductase activity very much better than did untreated extract. Both sodium fluoride and borax interfered with the oxidase activity slightly, if one may regard the alcoholic guaiac test as an indicator in this case.

An attempt was made to determine the influence of borax and sodium fluoride upon the respiratory ratio of cockroaches dying under the influence of these poisons, but the normal respiratory ratio, itself, varied so much for the roaches that no decided information could be gained. The intestinal tracts of the specimens used were apt to be gaseous, and the contents of the intestines were usually found to be well infested with infusoria, etc. This, it was believed, might account for the normally irregular respiratory ratio.

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## SUGGESTIONS FOR POSSIBLE PRACTICE.

### (a) SOLID AND LIQUID APPLICATIONS.

It will be observed that when the insecticides gained entrance into the insect tissues as purely contact agents, they did so, ultimately, in the fluid condition. Powdered solid contact insecticides gave off volatile bodies to be absorbed by the insect, or else the powdered agent became moistened and partly dissolved in exudations on the insect integument. Experiments showed that gases or volatile insecticides gained entrance to the insect tissues most rapidly. The "miscible oils" usually combined volatile and purely liquid agents. The liquid or the finely powdered solid often gained entrance through the spiracles to the larger tracheae where any volatile bodies that might be carried by the insecticides could then charge the air of the tracheal system. In the case of the powdered solid contact insecticide, the advantage evidentally lay in having the powder so fine and dry that it would adhere well and could sift readily into all crevices—even into the stigmata of the insect. Similarly, a weak surface tension for a liquid insecticide enabled it to flow into all irregularities of the area treated, and to penetrate often into the larger tracheae of the insect. Even in the case of lime-sulphur wash—which kills scales, perhaps in most cases, without ever having actually come in contact with the body of the insect itself—it would seem to be advantageous if the wash could be given a lower surface tension. The solution could then flow into crevices of the bark and thoroughly wet the scale-covering of insects that might otherwise escape. As is well known, soap cannot be used for the purpose, since it causes in the lime-sulphur solution a greasy lime-soap precipitate. A number of tests were carried out with the idea of finding agents which might be added to lime-sulphur, without injury, to lower the surface tension and cause it to spread on the bark of plants more readily. In order to be able to compare the "spread" of different samples of lime-sulphur dilutions readily in the laboratory, resort was had to what may be termed the "drop method." For example, the number of drops in 5 c. c. of water were counted as they came from a pipette. The same pipette was then washed out with lime-sulphur prepared by diluting a concentrate with a water solution of the agent to be tested. The number of drops in 5 c. c. of the latter lime-sulphur dilution were then counted from the pipette, and the ratio of the number of drops of water to the number of drops of lime-sulphur dilution was obtained. As long as the temperature of the liquids was practically the same and the drops were counted from the same cleaned pipette, the ratio between the number of drops in equal volumes of water and *any* lime-sulphur dilutions of approximately equal densities afforded a direct means for comparison of spread in the various dilutions. Actual trial on a tree covered with scale insects, showed that when this ratio equalled about 0.85*, the "Agent plus L. S. solution" had sufficient spread; that is, the spray readily flowed into crevices of the bark and wet the waxen scale coverings. The method was adapted from

* (e. g. $\frac{\text{Number drops in 5 c. c. of water}}{\text{Number drops in 5 c. c. of "Saponin-water-dilution of Conc. L. S."}} = 0.85$.)

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Mansier† who first suggested counting the drops in equal volumes of liquids under proper conditions of temperature, etc., for making a study of their surface tension in connection with insecticides. It was found that gelatine, glue, soluble albumen, and saponin could all be used in lime-surphur to increase the "spread" on the bark of a tree. The various agents were dissolved in the proper amount of warm water, after which the solution was added to concentrated lime-sulphur in making up the proper dilution. Glue and gelatine had to be used at the rate of about one pound to eleven gallons of lime-sulphur wash as diluted ready for use. The expense, therefore, would be too great to make their employment practical. This was true also in the case of albumen and saponin. Except for its expense, however, saponin seemed to be best of all the agents tried for the purpose. It dissolved readily, and a comparatively small amount added to the lime-sulphur increased the "spread" to the desired point without any apparent injury to the oxygen-absorbing power of the wash. Tests were made of this last point in the following manner:

A measured amount of the solution of saponin in water was added to a measured amount of concentrated lime-sulphur in a stender dish of standard volume and diameter; then, an equal sample of the same concentrated lime-sulphur, in a dish of the same diameter, was diluted with a volume of distilled water equal to the saponin solution used. The two dishes were introduced into exactly similar containers with equal volumes of air having the same known percentage of oxygen. At the end of a certain period of time (6 hours, for example) the oxygen percentage in each air-chamber was again determined, and from that, the volume of oxygen that had been absorbed. The volumes of oxygen absorbed in the saponin-lime-sulphur and in the check were practically the same—the greatest difference in three successive tests being no greater than the possible experimental error of the apparatus. When the dry powder was stirred directly into the lime-sulphur, however, the oxygen-absorbing ability of the solution was quite appreciably weakened. This was due no doubt to oxidation of the sulphides by air carried in with the dry powder. It was best, therefore, to dissolve the saponin in water, and then add that solution to the concentrated lime-sulphur.

Four tests were carried out to determine the influence of adding saponin, upon the rate at which water would evaporate from lime-sulphur (i. e. influence upon rate of drying). In every case, the evaporation was found to be a little more rapid from the lime-sulphur to which saponin had been added—as might be expected from the weakened surface tension. The difference, however, was not great—amounting to only 0.1 grm. of water from an area of 10.17 cm. in seven hours, on the average. This difference could be largely eliminated by adding salt (Na Cl) to the saponin-lime-sulphur solution. That is, salt had the effect of retarding the evaporation of water. It was used at about the rate first recommended in the original lime-sulphur salt-wash (i. e. about 18 lbs. to 100 gallons). Except in extremely dry weather or in a normally dry climate the salt would not serve a useful purpose.

Finally, all the tests tried seemed to confirm the first impression that saponin would be the ideal agent for lowering the surface tension of

†Mansier, M., 15 Jan. 1908, Bulletin de la Société des Agr. de France.

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lime-sulphur to obtain "spread," if only it were not so expensive. At the price of crude saponin, when these tests were carried out, it would add about $1.50 to the expense of each fifty-five gallons of lime-sulphur wash diluted ready for use against San Jose scale. The crude saponin, however, was just as good for the purpose as the *pure* obtained from Merck at a cost of more than five times the price of the crude product. Now the dry plant, *Saponaria officinalis* or *"bouncing bet"* was known to contain from thirty to forty per cent of extractives and it occurred to the author that perhaps the plant, itself, could be used in this connection. *Bouncing bet* grows about many farm yards, orchards, or gardens, coming up year after year from underground stolons. It is quite hardy, escaping cultivation and growing by roadsides, often, quite thickly. If the *plant* could be used, therefore, the orchardist might have a plot planted to *bouncing bet,* and prepare his lime-sulphur-saponin wash with only the extra expense of cutting, storing and extracting—which need not be great, it was thought. Accordingly, some plants were cut and dried in the early fall and laboratory experiments were carried out to determine whether "bouncing bet hay" could be used to satisfactorily increase the spread of lime-sulphur wash. Stated briefly, results proved that an excellent lime-sulphur spray mixture, as regards spread, etc., could be obtained by the use of an extract of either the green or the dry stems and leaves of *bouncing bet.* A good method of extraction was as follows:—the plant material was soaked in lime-water over night (12 to 18 hours, say) after which it was boiled about 30 minutes and then pressed out and strained. Thus an extract was prepared by using the dry stems and leaves of *bouncing bet* at the rate of 22lbs. of the plant material and 15lbs.* of freshly slacked lime to 50 gallons of water. This extract could be used to dilute concentrated lime-sulphur (of 26° Baume' and up) the required amount for use against San Jose scale; giving the spray mixture a very satisfactory spread. The added lime in the extract should prove useful, also, in assisting the lime-sulphur to soften the wax about the margins of the scale-coverings—in addition to the fact that it serves as a first class marker to show whether all parts of a tree have been covered.

When extract water from *bouncing bet,* prepared as explained above, was used in the place of ordinary water in the old formula (lump lime 20 lbs., sulphur flour 15 lbs., water 50 gallons) a homemade wash having a very high degree of spread resulted. A little of such a homemade wash was filtered, and the number of drops in 5 c. c. of water divided by the number of drops in 5 c. c. of the filtrate equalled 0.72. One homemade lot of lime-sulphur was prepared (in a smaller amount than is called for by the formula) while the plant material was still in the water. The formula follows: lime 20 lbs., sulphur 15 lbs., water 50 gallons, and 22 lbs. of the dry leaves and stems of *bouncing bet* to which enough water to wet them thoroughly had first been added. The mixture was kept boiling for forty-five minutes, after which the liquid was pressed out, and strained through coarse cheese cloth. The lime-sulphur appeared to have cooked up in good shape and the "drop ratio" for the spray solution was 0.73.

Whether these suggestions would actually prove profitable in orchard

*Less lime may be used. It is not absolutely necessary but it assists in softening and digesting the plant and in other ways.

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practice may be learned only by experience. If they should prove to be so, it is likely that commercial companies might produce a crude extract of *bouncing bet*—incorporating it in lime-sulphur concentrate, cheaply. A single test extending over several months indicated that saponin, in itself, did not cause lime-sulphur to deteriorate.

### b. FUMIGANTS.

The advantage of the fumigant—i. e. vapor or gaseous—contact insecticides are generally recognized. Likewise, disadvantages are equally well known. Generally speaking, gases diffuse rapidly and often penetrate where non-volatile liquids could never penetrate without damage—as in stored grain, clothing, etc. Also many gases or vapors are more rapidly absorbed by active insects than are any non-volatile liquid insecticides. A disadvantage, such as difficulty of confining a gas for the necessary period of time, may be overcome; but danger from fire and explosion in the case of carbon disulphide, and difficulty of application because of its danger to the operator in the case of hydrocyanic acid gas are disadvantages never entirely eliminated. It was in the hope of finding fumigants which might be safely substituted, in some cases, for the two fumigant insecticides just named that test work was carried on with ammonia and carbon tetra-chloride.

*Ammonia.* Experience gained with ammonia as an insecticide, during the time its influence upon the respiration of insects was being studied, led to the belief that perhaps ammonia gas from compressed or liquified ammonia might be applied as an insect fumigant with greater ease and with less danger than hydrocyanic acid gas. Experiments carried out with *Calandra granaria, Silvanus surinamensis*, and larvæ of *Tenebroides mauritanicus* enclosed with a little dry wheat in tight glass receptacles showed that the insects could *all* be killed with three to four per cent ammonia in twenty to twenty-two hours, and with nine to ten per cent in six to seven hours. In fact, it was possible to kill in most cases at lower percentages, and in shorter periods when using the higher percentages of ammonia—but death was always certain when the gas was used at the rates given.

A few germination tests were made with dry wheat treated with different percentages of ammonia, 100 grains being used in each check and in each treated sample. It was found that where the percentage of ammonia was kept up to about 3.2 for 22 hours the germination was ruined. At 10 to 13.5 per cent for an interval of eight hours, however, the per cent of injury from ammonia to germination was less than one; for ten hours at 11.9 per cent the injury was over fifty per cent.

Following the various laboratory tests, two fumigations of the college mill-room were carried out with ammonia gas derived from cylinders of compressed and partly liquefied ammonia. The room was closed as tightly as any plastered room with closely fitting windows may be closed. The iron tube of ammonia was placed on a platform balance outside, and the ammonia gas was conducted through a tube (properly fitted under the door) almost to the center of the room. Two wire cages of insects were left in the open where they could be seen from the outside through the glass of the mill-room door. Two other cages were buried three and six inches, respectively, in dry wheat. There were

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about fifteen bushels of sacked wheat, and a little corn in the ear, stored in the room. In the first test (Oct. 7, 1911) ten pounds of ammonia were passed through the tube. Since the air-space where the gas expanded was 7166 cubic feet, the percentage of ammonia was about 3.1 in the early part of the test. The experiment ran between nineteen and twenty hours. A caged specimen of the large American cockroach was still alive at the end of the test, but he was so under the influence of ammonia that he died from the effects later. *S. surinamensis* and *C. granaria* in one of the exposed cages were motionless. Some of the *Calandra* recovered in fresh air enough to move their legs, but none ever recovered entirely. All the beetles in the two cages buried in the wheat were active at the end of the test and were still alive and normal three days later. The next day living specimens of the saw-tooth grain beetle were found between the grains of the corn in the ear.

On November 21, 1911, the mill was again fumigated with ammonia in the same manner as in the first test; but this time 32.5 lbs. of the compressed ammonia were used—i. e., one pound of ammonia gas to 223.9 cubic feet of air space. This gave about ten per cent of ammonia in the room. One hour and fifteen minutes were used in introducing the charge, and the room was kept closed (over night) for seventeen hours. Wire-caged insects had been introduced again, as well as several large sacks of infested wheat. About twenty bushels of new corn that was not very dry was present also. The latter became very decidedly darkened during the test. Wheat was always more or less darkened by ammonia fumigation in the laboratory tests—as well as in the mill test—but the dryer the grain, the less noticeable was the darkening in every case. In this test, a caged cockroach (*P. americana*) became quiet by the time the charge had been two-thirds introduced. The roach was dead at the end of the test, as were also the caged beetles left in the open. Mice were killed. One mouse was seen to come out on the floor and die when fumigation had been going for forty-five minutes. Insects about one inch deep in the wheat were killed, but caged beetles (saw-tooth grain beetle and grain weevil) buried in the center of a sack of wheat were active at the end of the test. In both the mill tests brass and copper parts of the mill machinery were covered with vaseline, which protected them perfectly from action by the ammonia. The compressed ammonia was certainly convenient to apply; and at three to four per cent, fumigation could be carried on with the gas at a reasonable cost, since iron cylinders of liquefied ammonia could be obtained at that time for twenty-nine cents per pound. Considerable of the ammonia was absorbed by the grain; but after a few hours airing, the odor disappeared. The darkening of the grain seemed to be an undesirable feature, however. Mr. Spragg of the Farm Crops Department prepared flour from three kinds of wheat treated in the first mill experiment—and also, from the three corresponding check samples of wheat. There was no taste of ammonia on any of the flour, but that from two of the treated samples of wheat was quite noticeably darker than the corresponding checks. A Lansing miller, who was kind enough to slick the samples of flour and judge them, decided that the action of the ammonia on the wheat had undoubtedly injured its milling qualities commercially. To be sure, the grain was really darkened, noticeably, to a depth of only two or three inches

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in a large container; but at that depth, the insects were not killed. For the reason just stated the mill experiments with ammonia were discouraging—although it appeared that the gas, in some instances, might prove to be a desirable fumigant for insects.

*Carbon Tetrachloride.* Early in the year 1910, Professor Pettit was urged in behalf of the Michigan Millers to find, if possible, some volatile non-inflamable liquid which might take the place of carbon disulphide as a fumigant for grain in bins. It was suggested to him by Professor Kedzie of the chemistry department that perhaps carbon tetrachloride might have the qualities desired. Following this suggestion, a series of comparative tests with carbon disulphide and carbon tetrachloride were carried out by Professor Pettit, Mr. M. A. Yothers (who was connected with the department at that time), and the writer, working together. The tests were made in large glass flasks with rubber stoppers. Among the insects in the infested grain used in these tests were the following beetles determined by Prof. F. H. Chittenden of the U. S. Bureau of Entomology:

*Rhizopertha dominica,*
*Latheticus oryzæ.*
*Laemophlaeus pusillus,*
*Calandra oryzæ,*
*Tribolium ferrugineum.*

A great many *Silvanus surinamensis* were also used. In these tests carried out in the tight glass flasks, practically all beetles were killed by carbon disulphide used at the rate of ¼ dram to a cubic foot of air space. It took 1½ drams of the tetrachloride of carbon to accomplish the same result (at about 70° F.). That is, compared with carbon disulphide, six times as much carbon tetrachloride was required to accomplish effective fumigation. The tests were run from seventeen to twenty-four hours. It should be stated that the liquid insecticide in every case was dropped upon a thin piece of absorbent cotton, which was suspended at the center of the flask. Thus, the broad surface of the cotton enabled the fluid to evaporate rapidly. The liquid carbon tetrachloride was found to be entirely non-inflammable—and its vapor, non-explosive.

Results of the experiments just described were not published at the time—mainly because the expense for effective fumigation with carbon tetrachloride seemed so great as to be almost prohibitive. Dr. Britton of the Connecticut Experiment Station had given, in 1908, his experiments with carbon tetrachloride used as a fumigant against scale insects on nursery trees.*

Later, Feb., 1910, Mr. Albert P. Morse published a note on "Carbon Tetrachloride vs. Carbon Bisulphid" as a fumigant used in the control of grain and natural history pests.† Mr. Morse stated that "for large cases a strength of one quart to fifty cubic feet is desirable—practically twice that of carbon bisulphid, of which a pint to fifty cubic feet is sufficent."

In October, 1911, Professor F. H. Chittenden and Mr. C. H. Popenoe of the U. S. Department of Agriculture published a paper on experiments carried out with the same chemical used as a substitute for car-

*Journal of Economic Entomology, Vol. 1, No. 2, p. 111.
†Journal of Economic Entomology Vol. 3, No. 1, p. 104.

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bon bisulphid in fumigation against insects.* The authors found that "if the material were a cheap product, it might prove a substitute for carbon bisulphid if used in strength greater than ten pounds to one thousand cubic feet."

Later still (May, 1913), Professor H. Garman of the Kentucky station stated that, as the largest amount of carbon tetrachloride used in a series of tests, 20.8 ozs. to 100 cubic feet killed 100 per cent of the insects in nine cases out of twelve.†

In the Spring of 1914, a request came from the J. W. Knapp Department Store of Lansing, Michigan, asking for some safe means of insuring valuable furs, stored in a small room, against moths during the summer. The "fur room" was 4x6½x6½ feet—the side walls tightly built of matched lumber, the ceiling of glass. It was located in the large cloak and coat department room, where it was very accessible; but any fumigant used had to be as inoffensive as possible, without especial danger to human life, and without the entailment of extra fire risk. Carbon tetrachloride suggested itself as the possible, satisfactory fumigant in this case. Further laboratory tests had shown the writer that with ordinary wooden enclosures, which were not practically gas-tight (as was the case with the glass flasks), perfect fumigation could not be obtained at usual room temperatures (68° to 70° F), even when the carbon tetrachloride was exposed in a wide vessel. The vapor slowly escaped from the walls of such enclosures, and evaporation did not go on rapidly enough at even 70° F. to bring about the necessary concentration for perfect fumigation. It was necessary to use heat and vaporize the liquid quickly. Dr. Britton had experienced a somewhat similar difficulty in volatilizing this liquid in his experiments with nursery stock. He finally resorted to the use of heated cast iron pans for generating the vapor more quickly (citation given above). Recommendation was made in this instance, therefore, that six pounds of carbon tetrachloride be vaporized from wide, heated pans placed near the ceiling of the "fur room"—and that the charge be started immediately after closing hours in the evening. According to this recommendation, the liquid carbon tetrachloride was used at the rate of about 3.55 pounds to 100 cubic feet of room space. Heat for vaporization was supplied by hot, flat soapstones laid on iron brackets. The wide pans of carbon tetrachloride were set on the hot soapstones and the room was quickly closed. In the case of the first charge tried, the stones had not been made hot enough and not quite all the liquid insecticide had evaporated even after twenty-four hours. Several adult moths (*Tinea biselliella*) had been placed in a wire cage in the room. These were quiet when the cage was removed at the end of the twenty-four hours period, but after about four hours in fresh air two moths recovered enough to be able to move their legs. However, none ever recovered entirely. Another charge was made with six pounds of the carbon tetrachloride, and this time the soapstones were made very hot so that the liquid vaporized rapidly. A cage of moths could be observed through the glass roof of the room. They quickly became quiet. Before morning all the liquid insecticide had been vaporized. The cage was removed after thirty-six hours, and the moths were

*Bulletin No. 96, Part IV, 1911; Bureau of Entomology, U. S. Dept. of Agriculture.
†Kentucky Sta. Bulletin No. 172, p. 200.

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kept under observation at intervals for one day; none of the insects showed any recovery. (See tables IV and V for the effect of carbon tetrachloride upon reductases and catalases). This last charge of insecticide vapor was considered satisfactory; and following it, similar fumigations were made at intervals of about five weeks, on the average, from May until October. The large room, in which the "fur room" was located, was well ventilated and nothing of a disagreeable nature was ever experienced from the fumigation. All the furs came through the Summer in fine condition. The company management was so well pleased that the same method is being used with the furs again in the Summer of 1915. Moreover, Mr. Armstrong, who was in charge, reported that this method of caring for the furs had proven to be cheaper than 'cold storage"; and in addition, it afforded the very great advantage of convenience in having the furs where they were easily accessible. Carbon tetrachloride cost the company twenty-seven cents per pound.

### C. HEAT AS AN INSECTICIDE.

Finally, suggestions relating to possible practice should certainly call attention to heat as an insecticide. The effect of heat upon oxidases, catalases and reductases in the tissues of *P. cornutus* and various other insects has already been given earlier in this paper. No more efficient means than heat was found for destroying the activities of these three agencies of the tissue cells; it was shown that when specimens of *P. cornutus* were killed by the least degree of heat that could be effectively used, the activities of reductases, oxidases, and catalases were injured in a greater or less degree. The effect of different degrees of heat in coagulating the various soluble proteins in animal tissues is well known. It should be added here that fatal injury to the insects, and noticeable injury to one or more of the three kinds of enzyme-like bodies named, seemed to occur just before the first agglutination of protein took place. The reductase was the most susceptible. In case of clear, filtered water extracts of the tissues of *P. cornutus*, which were heated up very slowly and gradually, the soluble catalase showed its greatest loss in activity earlier than the guaiac oxidase. The latter lost its principal activity at the moment of separation of the chief or largest protein precipitate.

The fatal temperature, in the case of insects, varied considerably with the species and with the length of time the insects were exposed. No insects were tried, however (in small enclosures), which required a temperature of more than 122° F. maintained for a period of three hours to cause death; and at that temperature, death usually resulted quickly. Now, 122° F. is a comparatively low temperature and many plants can stand exposure to even higher temperatures for several minutes without appreciable injury. It is very well known that cabbage can endure hot water or hot soapsuds much better than can the common "cabbage worm." In fact, when cabbage is heading, hardly any safer or better method for killing cabbage-worms in the home garden is practiced than the use of hot soapsuds. During the last five or six years, Professor Dean of the Kansas State Agricultural College and Experiment Station has introduced heat as a comparatively cheap and efficient method of controlling all classes of mill-infesting in-

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sects.* The method has been put to the test in several other states and is now recognized as the best method of controlling insects in well built, steam-heated mills.

In view of the above facts it has seemed to the author that perhaps heat might be applied to advantage as an insecticide for many insects in situations where it has never been the practice to use it. A few, more specific suggestions may be made. There have never been any extensive tests carried out (so far as we have been able to find) to determine whether heat might not be used profitably in certain instances to clean some kinds of nursery stock of insect pests. One opportunity was afforded the author of making a limited test of the possibilities along this line. Forty-four one year old apple-stocks were given by the Department of Horticulture for the test. It had been found by trial that San Jose scale on thickly infested twigs could be killed by submerging them for five minutes in water heated to 130° F. The green apple aphis was killed within one-half minute in water at that temperature. The test with the apple-stocks was carried out, therefore, to learn something of the effect, upon the stocks themselves, of dipping them in water at certain temperatures for different periods of time. The bundle of stocks, wrapped in sphagnum, had been kept all winter in the basement of the cold storage plant at the college. They were still almost entirely dormant on May 4th, 1914, when the test was started. Ten average stocks were picked out for a check—not to be treated, but planted just as they came from the storage. The remainder were given treatment as follows:—

(1) 5 stocks—tops, only, dipped at 130° F. for 5 mins.
(2) 5 stocks—tops, only, dipped at 130° F. for 10 mins.
(3) 5 stocks—tops and roots dipped at 130° F. for 6 mins.
(4) 5 stocks—tops, only, dipped at 140° F. for 5 mins.
(5) 5 stocks—tops, only, dipped at 140° F. for 15 mins.
(6) 5 stocks—tops and roots dipped at 140° F. for 20 mins.
(7) 4 stocks—tops and roots dipped at 150° F. for 10 minutes.

All the stocks were then planted in a row close together at the same depth in the same kind of soil.

The checks or untreated stocks leaved out several days ahead of the treated plants, but all of the latter finally came into leaf, and were still alive in the fall—except the four stocks which had been treated in water at 150° F. for 10 minutes. Those four plants had been killed, evidently by the treatment. Examined on May 21, 1915, most of the young apple trees were in almost full leaf. The dead and injured trees could be easily recognized. Nine of the trees in the check were alive and one dead. By numbers, the condition of the treated trees was as follows:—

(1) 5 trees alive.
(2) 4 trees alive; 1 tree dead.
(3) 3 trees alive; 2 trees dead.
(4) 3 trees alive; 2 trees dead.
(5) 5 trees alive; 3 of them with 3 or 4 inches of stock dead at the top.

*Bulletin No. 189, 1913, Kansas Agr. Expt. Station.

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(6) 2 trees alive; 3 trees dead.
(7) These trees were all dead last Fall.

It will be observed that some of these plants stood exposure to a higher temperature for a longer period than would be necessary to kill San Jose scale. This test is not offered as in any way conclusive, however. It is described here in order to better call attention to the suggestion that possibly a careful and thorough investigation along this and similar lines might be worth while.

Most household pests succumb readily to heat. For example, adults of one of the common clothes-mothes (*Tinea biselliella*) may be quickly killed at 119° F. A hot flat iron has often been recommended as a means of killing the larvæ of moths in clothing—but might not some practical and safe means of applying heat be arranged to insure valuable clothing in chests or closets against moths? Thus, there are many possibilities for heat, as an insecticide, that have never been carefully and systematically tested as to their larger practicability.

## GENERAL CONCLUSIONS.

Reductases, catalases and oxidases were found in water extracts and in the insoluble pulp of the tissues of *P. Cornutus* and other insects. Moreover, almost certain evidence indicated that the same three kinds of enzyme-like bodies exist in the intact tissues of living insects.

Heat of certain intensities, and the several contact insecticides studied (gasoline, carbon-disulphide, hydrocyanic acid gas, sodium fluoride, etc.), when used at a concentration sufficient to kill insects, deleteriously affected the activities of reductases, catalases and oxidases—usually in unequal degree, thus disturbing the natural or normal balance of such activities.

If the catalase, oxidase, and reductase activities are actually of as vital importance to the life processes of the tissue cells as certain evidence indicated, then the deleterious action of the contact insecticides studied in this connection must be an important factor—perhaps, in some cases, the *determining* factor—in causing the death of treated insects.

A study of the influence of the various contact insecticides upon the life processes in nervous tissue cells seems of next importance in this connection.

Fat or fat-like membrances (e. g., lard and lanoline) absorbed gasoline-vapor (and chloroform-vapor) from air charged with that vapor, and the absorbed vapor rendered the membranes less permeable to oxygen. This finding may, in part, account for the fact that less oxygen was used by an insect deeply under the influence of gasoline, since a similar condition existed—in that, under such circumstances, the lipoids of the living, oxygen-absorbing cells, and of the body fluids surrounding them, were impregnated with gasoline. So also, the same finding may help to explain the fact that, in the presence of air containing gasoline vapor, less hydroquinone was oxidized in an "insect tissue extract plus hydroquinone solution" (in which the reductase had mostly passed) than was the case when the same extract was in pure air.

Waxen membranes which had been thoroughly wet with lime-sulphur

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solution were found to be less permeable to oxygen than before they were treated with the solution. Thus lime-sulphur, in addition to its effect as described in a former paper, would render the waxen covering of a scale insect less permeable to oxygen.

Pupæ of the Luna moth, and adults of *Passalus cornutus* in a dormant condition from cold, absorbed much less gasoline-vapor or vapor of ether in air than did the same insects when they were most active, at a warm room temperature, in air charged with practically the same percentage of vapor. This lowered absorption capacity, which was found to accompany the dormant condition, may furnish the chief explanation of the fact that insects, dormant from cold, are harder to kill by ordinary fumigants and by those contact sprays which depend partly upon volatile insecticide ingredients for their effectiveness.

It was found that certain non-volatile, powdered solids were able to act as effective contact insecticides when used on certain insects. Such dry, powdered insecticides stuck fast in exudations on portions of the insect body, where they became partly dissolved, after which they appeared to be slowly absorbed through the body-integument.

Both powdered borax and sodium fluoride may kill cockroaches in the manner of purely contact agents, but normally they become stomach poisons as well—since the roaches regularly lick and swallow some of the powder in cleaning it from their bodies.

In the case of powdered solid contact insecticides, the advantage seemed to lie in having the powder so fine and dry that it could sift readily into all crevices and could adhere well. Similarly, other things being equal, a weak surface tension gave a liquid contact insecticide an advantage, enabling it to thoroughly wet the bodies of insects and to flow into all irregularities of the area treated.

Among several substances which were found to increase the "spread" of lime-sulphur solution, saponin or extracts taken directly from the stems and leaves of *Saponaria officinalis* (*bouncing bet*) seemed to be best. It is suggested that perhaps the use of extracts from "bouncing-bet hay" with lime-sulphur solution might prove profitable in orchard spray-practice.

Experiments with ammonia (derived from dry liquefied ammonia) as a fumigant for mill insects were rather disappointing; but the liquified ammonia was easy to apply and might prove to be a desirable fumigant for insects in some instances.

When carbon tetrachloride was compared with carbon disulphide as to its action on grain insects in tight flasks, six times as much of the former was required for effective fumigation. The carbon tetrachloride was vaporized with heat and satisfactorily used, at the rate of 3.55 lbs. for 100 cubic feet of air space, to insure furs against moths—fumigation being repeated every five weeks during the summer months. The charge as used killed adults of *Tinea biselliella*.

Evidence indicates that heat might be applied to advantage as an insecticide in many situations where it has never been the practice to use it.

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## PLATE I.

Fig. 1. Sample of thick creamy extract in the left stender dish was treated strongly with CS, and $\frac{M}{10}$ hydroquinone was added later in the presence of the $CS_2$.

Check extract to the right (not treated) had the same amount of $\frac{M}{10}$ hydroquinone added, at the same time as the treated extract.

The darker color of the check shows the greater oxidation of the hydroquinone to quinone.

Fig. 2. Shows the form of sealed tube in which the reducing action of insect-tissue extract toward methylene blue, indigo carmine, etc., was studied.

Fig. 3. First cup to the left shows the darkened solution of tyrosin, oxidized under the influence of a crushed elytra (thoroughly cleaned with alcohol) of an old adult *P. cornutus*.

Middle cup contains clear unoxidized solution of tyrosin with crushed elytra which had been heated to boiling for 10 minutes.

Cup to the right—check, containing only tyrosin solution which remained clear during the 7 days of the test.

Fig. 4. Cockroach (*P. americana*), showing the head and arrangement of the white bristol-board collar to prevent the insecticide powder, with which the body was treated, from reaching the insect's mouth.

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MICHIGAN AGRICULTURAL COLLEGE

EXPERIMENT STATION

DIVISION OF SOILS

# EFFECT OF TEMPERATURE ON SOME OF THE MOST IMPORTANT PHYSICAL PROCESSES IN SOILS.

BY
GEORGE J. BOUYOUCOS

EAST LANSING, MICHIGAN
1915

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## INTRODUCTION.

Temperature is considered to affect to a greater or less degree practically every physical process in the soil. Some of the most important processes thus influenced include the gravitational flow of water, capillary movement and retention of moisture, diffusion and flow of gas, etc. Our present knowledge concerning the influence of temperature upon these factors in the soil consists almost wholly of *a priori* prediction from the known laws of viscosity, surface tension, and expansion of liquids and gases as affected by temperature. There appears to exist practically no investigation verifying the validity of these laws in the case of soil media. These physical laws have been deduced from homogeneous media, and consequently from ideal cases, and it is not safe from *a priori* considerations to assume that they apply equally well to soil of such a heterogeneous composition. The heterogeneity and manifold properties of the soil mass introduce many unforeseen factors which may give entirely unexpected results. Indeed, such is the case with many of the aforesaid processes.

It is the purpose of this bulletin, therefore, to present data showing to what degree temperature affects the most important physical processes in the soil, and incidentally to indicate how far the claim of the applicability of the physical laws is confirmed or disproved.

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## EFFECT OF TEMPERATURE ON THE MOVEMENT OF WATER VAPOR AND CAPILLARY MOISTURE IN SOILS.

### MOVEMENT OF MOISTURE FROM WARM TO COLD COLUMN OF SOIL OF UNIFORM MOISTURE CONTENT.

The surface tension and viscosity of water decrease with rise in temperature to the extent shown by the data in table 1.

TABLE 1.—RELATION OF TEMPERATURE TO THE SURFACE TENSION AND VISCOSITY OF WATER.

| Temperature C°. | Surface tension. | Viscosity. |
|---|---|---|
| 0 | 100. | 100. |
| 10 | 97.96 | 73.32 |
| 20 | 94.32 | 56.70 |
| 30 | 91.62 | 45.12 |
| 40 | 88.46 | 36.96 |
| 50 | 85.52 | 30.17 |

It will be noted that the degree of diminution with rise in temperature is considerably greater in the case of viscosity than in surface tension.

During the warm part of the year the soil at the upper depths maintains a rather marked temperature gradient which reverses itself between day and night to the depth that the diurnal amplitude of temperature oscillation extends. This diurnal change of temperature gradient occasions an alteration in surface tension and viscosity of the soil moisture, the amount depending upon its variation at the different depths. Since capillary action is said to depend upon surface tension, and facility of movement upon viscosity, then there should occur an upward and downward movement of moisture as the temperature gradient changes diurnally. During the day, for example, the temperature of the soil is highest at the surface and diminishes with depth; the surface tension and the viscosity of soil moisture, are lowest at the surface and rise with depth; consequently the movement of moisture should be downward. During the night, the reverse is true; the soil temperature is lowest at the surface and increases with depth; the surface tension and the viscosity of the soil water are greatest at the top and diminish downward with increase of temperature; hence, the water translocation should be upward.

These considerations are *a priori* deductions from the laws of surface tension and viscosity in their relation to temperature. Whether or not they are valid, however, is heretofore not known; since there appear to be no experimental data bearing directly upon the subject.

With the object in view of ascertaining this important and much desired information an investigation of the problem was undertaken. The general method of procedure consisted of placing soil of different but

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uniform moisture content in brass tubes 8 inches long and 1½ inches in diameter, closing both ends with solid rubber stoppers, and keeping one-half of the soil column at a high temperature and the other half at a low temperature for a certain length of time, then determining the percentage of moisture of the two columns, and attributing any difference in water content to thermal translocation. There were only two amplitudes of temperature employed, 0° to 20° C., and 0° to 40° C., i. e., one-half of the soil column was kept at 0° C. and the other half at 20° and 40° C. For producing these temperature amplitudes wooden boxes were used which contained melting ice and warm water separately and their temperatures were maintained constant by the addition of ice and hot water respectively.

The movement of moisture from warm to cold soil was studied in two different ways: (1) when the column of soil stood horizontally, and (2) when it stood vertically. For the first case, the wooden boxes used were 22 inches long, 10 inches wide, and 20 inches deep, having a wooden partition in the center which contained perforations of the size to fit the tubes. One compartment contained melting ice and the other water at the desired temperature. To prevent any exchange of water between the two compartments the edges of the partition and the holes through which the tubes passed were made water-tight by means of paraffin. For the second study, the employment of two boxes was necessary. One box, which contained melting ice, was 24 inches long, 10 inches wide, and 13 inches deep. The other box, which contained water at the desired temperature, was made to fit the inner side of the first box and was 13 inches long, 7 inches wide and 11 inches deep. The bottom of the small box was supplied with holes in which to place the tubes. The size of the perforations was made to fit the tubes tightly. To make the small box also water proof the crevices surrounding the tubes were sealed with melted paraffin. The small box was then put upon supports in the large box. The latter was filled with melting ice up to and touching the bottom of the former. The water in the upper box was kept at the desired temperature. A diagram of both set of boxes is shown in figure 1. All the boxes were well insulated, and since they were big and contained large volumes of water the temperature could be kept to within small variations for long time. The water was stirred occasionally, to maintain uniformity of temperature throughout the mass.

The temperature amplitudes employed are within the upper limit of the diurnal amplitudes of temperature at the upper depths in the soil but they are too high for the range of temperature that exists at any one time between the various adjacent depths.

The duration of each experiment was about eight hours. This time limit was calculated to represent approximately the length of time that the day and night soil temperature gradient is most marked.

The effect of temperature on the movement of moisture in soils of uniform moisture content was investigated in 5 diverse classes of soil, namely: Miami light sandy loam, Miami heavy sandy loam, Miami silt loam, Clyde silt loam and Miami clay. Each soil contained a large number of different moisture contents. These various moisture contents in each soil ranged from very low to very high.

To procure very uniform moisture content throughout the soil column each soil, after it was moistened to the desired degree, was passed through

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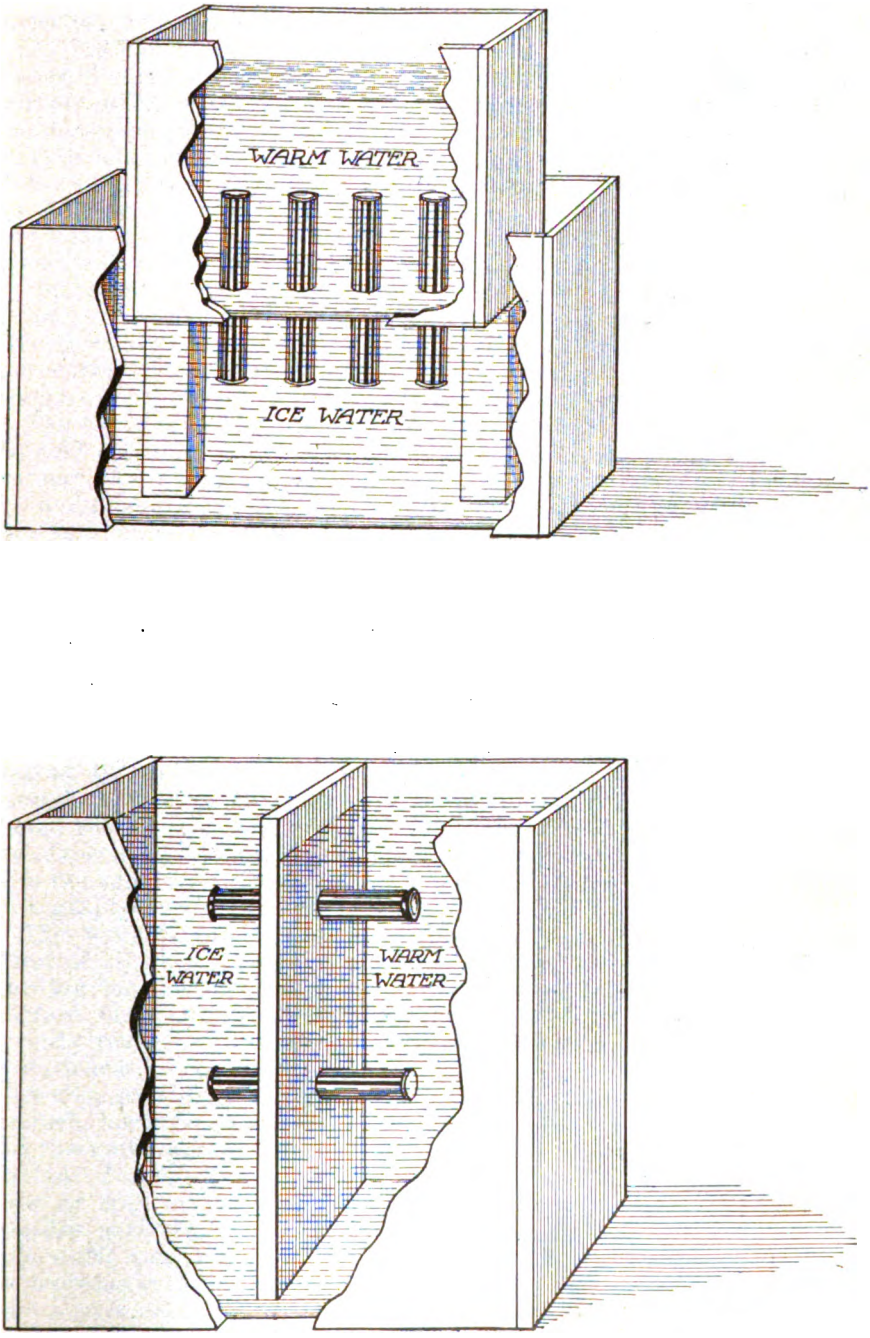


FIG. 1. APPARATUS FOR MEASURING THE THERMAL MOVEMENT OF MOISTURE IN SOILS EITHER VERTICALLY OR HORIZONTALLY.

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TABLE 2.—PERCENTAGE OF MOISTURE MOVED FROM WARM TO COLD COLUMN OF SOIL OF UNIFORM MOISTURE CONTENT.

| Kind of soil. | Percentage of moisture. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sandy loam: | | | | | | | | | | |
| Beginning of experiment | 2.29 | 3.86 | 6.45 | 7.50 | 8.48 | 9.95 | 10.94 | 13.75 | 15.96 | ..... |
| Movement from 20 to 0°C | 0.102 | 0.296 | 0.792 | 0.900 | 0.530 | 0.520 | 0.466 | 0.340 | 0.100 | ..... |
| Movement from 40 to 0°C | 0.410 | 1.064 | 1.97 | 2.882 | 1.715 | 1.467 | 1.30 | 0.97 | 0.30 | ..... |
| Heavy sandy loam: | | | | | | | | | | |
| Beginning of experiment | 4.20 | 6.52 | 9.08 | 10.42 | 12.43 | 14.02 | 16.03 | ..... | ..... | ..... |
| Movement from 20 to 0°C | 0.160 | 0.631 | 0.930 | 0.721 | 0.582 | 0.491 | 0.21 | ..... | ..... | ..... |
| Movement from 40 to 0°C | 0.59 | 1.75 | 3.02 | 2.40 | 1.98 | 1.40 | 0.42 | ..... | ..... | ..... |
| Silt loam: | | | | | | | | | | |
| Beginning of experiment | 4.29 | 8.06 | 9.76 | 11.28 | 14.441 | 15.95 | 17.63 | 19.30 | 21.42 | 23.51 |
| Movement from 20 to 0°C | 0.138 | 0.736 | 1.024 | 1.180 | 1.190 | 1.10 | 0.85 | 0.48 | 0.35 | 0.21 |
| Movement from 40 to 0°C | 0.471 | 1.98 | 2.65 | 3.276 | 3.68 | 3.58 | 2.50 | 1.75 | 1.02 | 0.45 |
| Clyde silt loam: | | | | | | | | | | |
| Beginning of experiment | 7.56 | 12.51 | 14.98 | 17.59 | 18.80 | 21.55 | 22.76 | 29.98 | 34.57 | ..... |
| Movement from 20 to 0°C | 0.122 | 0.46 | 0.89 | 0.96 | 1.07 | 0.99 | 0.83 | 0.62 | 0.20 | ..... |
| Movement from 40 to 0°C | 0.409 | 1.72 | 2.07 | 2.45 | 3.27 | 2.82 | 2.30 | 1.36 | 0.51 | ..... |
| Clay: | | | | | | | | | | |
| Beginning of experiment | 9.70 | 18.38 | 19.29 | 20.69 | 22.98 | 29.88 | ..... | ..... | ..... | ..... |
| Movement from 20 to 0°C | 0.248 | 0.72 | 0.99 | 0.73 | 0.70 | 0.681 | ..... | ..... | ..... | ..... |
| Movement from 40 to 0°C | 0.672 | 2.60 | 3.29 | 2.50 | 2.12 | 1.88 | ..... | ..... | ..... | ..... |

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a sieve and then mixed thoroughly. It was then placed in the tubes and packed uniformly by allowing the tubes to fall in a vertical position from a certain height a definite number of times.

At the end of each experiment the warm column was separated from the cold column of soil by means of a spatula. This was done by drawing out all the soil from that warm section of the tube which extended up to the plane of the partition and allowing for the cold column of soil all the soil that was contained in that cold section of the tube up to the other plane of the partition, and also that portion of the soil contained in the tube under the hole of the partition. This last part of the soil was accorded to the cold column of soil because its temperature is intermediate between the opposite temperature extremes and it was desired to make the lines of demarcation between the two columns of soil as prominent and distinct as possible. The moist soils were dried in an electrical oven for about 20 hours at a temperature of 105° C., and the percentage of moisture content was calculated on the dry basis. The weights were always made on a sensitive chemical balance.

The fact has been mentioned that the mobility of moisture from warm to cold column of soil was studied in two different ways: (1) when the column of soil stood horizontally, and (2) when it stood vertically. The data obtained from both series of experiments show that if the same percentages of moisture were employed practically the same results were obtained, no matter whether the soil columns remained in the horizontal or vertical position. For sake of brevity and simplicity of presentation, therefore, only the results of the series of experiments wherein the soil column was held in the vertical position, will be presented here. These experimental data together with their diagramatic representations are submitted below. Table 2 contains the different soils with their various moisture contents, and the percentage of moisture moved from the column of soil at 20° to the column of soil at 0° C., and from the column of soil at 40° to the column of soil at 0° C. The percentage of moisture moved represents the difference between the percentages of moisture found in the cold and warm columns of soil respectively at the end of the experiment; at the beginning of the experiment the moisture content was the same in both columns of soil. Figure 2 represents all these data in a graphical form.

The foregoing data present many important and remarkable facts. First of all, they show most emphatically that the *a priori* prediction regarding the thermal movement of moisture as deduced from the laws of surface tension and viscosity in their relation to temperature, is not strictly realized. According to these laws the amount of water moved from warm to cold column of soil should be the same for all moisture contents, providing the soil mass exerts no influence upon water; inasmuch, however, as the soil does exert an adhesive force for water, then the thermal translocation of moisture should increase with rise in water content. *Instead, the percentage of water moved from warm to cold column of soil, at both temperature amplitudes, increases regularly and rapidly with increase in moisture content in all the different types of soil, until a certain moisture content is reached and then it commences to decrease with further rise in percentage of water. The results plot then into a parabola, with a maximum point, instead of a straight line.* This maximum point of water thermal translocation is significant in at least

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two ways: (1) it is quantitatively about the same for all diverse classes of soil, and qualitatively the same for both amplitudes of temperature, and (2) it is attained at entirely different moisture contents in the various soils, and at a comparatively low percentage of moisture. On referring to the data in table 2 it will be seen that the maximum thermal

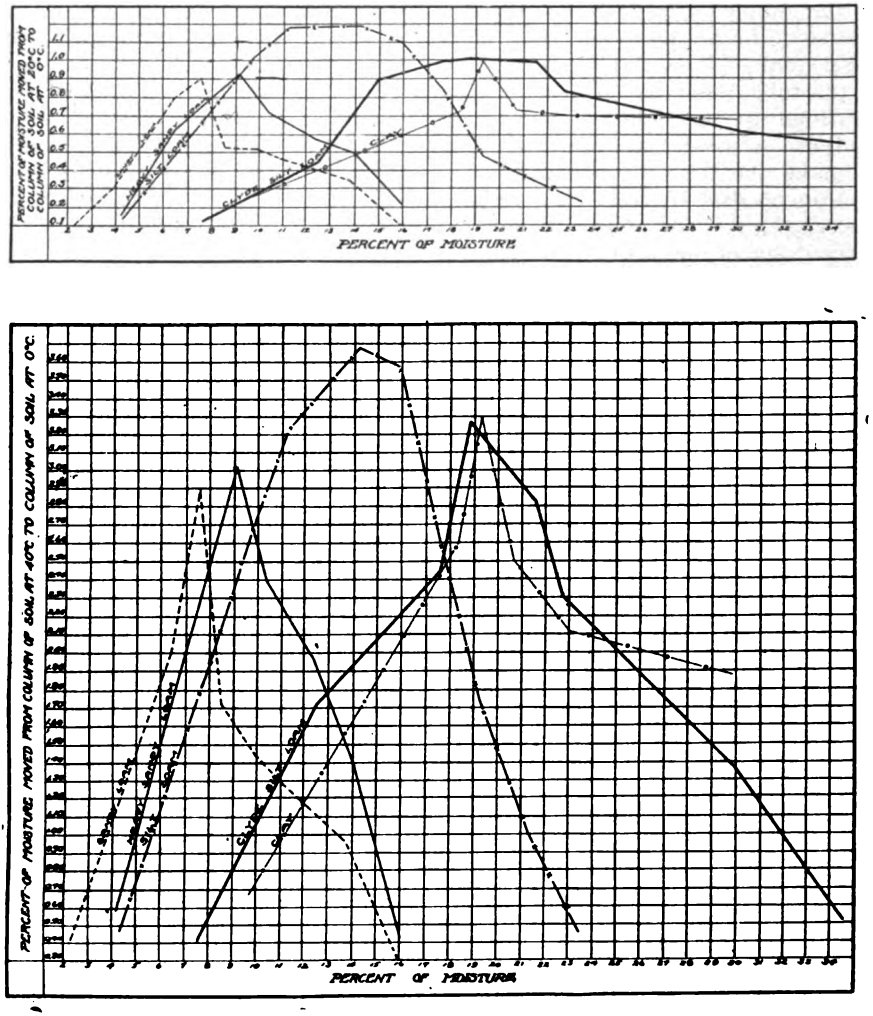


FIG. 2. CURVES SHOWING MOVEMENT OF MOISTURE FROM WARM TO COLD COLUMN OF SOIL OF UNIFORM MOISTURE CONTENT.

water transference at the amplitude of 20° C. is 0.90 per cent for light sandy loam, 0.93 for heavy sandy loam, 1.19 for silt loam, 1.07 for Clyde silt loam, and 0.99 for clay; at the temperature amplitude of 40° C., it is 2.88 per cent for light sandy loam, 3.02 for heavy sandy loam, 3.68 for silt loam, 3.27 for Clyde silt loam, and 3.29 for clay. It should be

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noted that the percentage of thermal motion of water increases more than proportionally with temperature. The temperature of 40° C. for instance, is only twice as great as 20° C. while the percentage of moisture moved is three times greater in the former case than in the latter. The water content of the various soils at which the maximum thermal translocation occurs is 7.50 per cent for light sandy loam, 9.08 for heavy sandy loam, 14.21 for silt loam, 18.80 for Clyde silt loam, and 19.29 for clay.

Obviously then, the maximum thermal water movement depends upon a definite condition of moisture of any particular soil; a deviation from this definite degree of moisture in either direction causes a decrease in thermal movement of water. Since this definite percentage of moisture at which the greatest quantity of water is able to move from warm to cold column of soil appears to be a specific constant or characteristic of the various soils, it is proposed to designate it as *thermal critical moisture content.* A thermal critical moisture content may be defined then as that percentage of moisture in a soil which allows the greatest amount of water to move from a warm to a cold soil at any amplitude of temperature.

A further examination of the preceding experimental data shows that the thermal movement of moisture is extremely sensitive to the amount of water present in a soil. It will be noted that by increasing or decreasing the percentage of soil water by small degrees the thermal movement varies very markedly in either direction. From this it follows that the thermal critical moisture content must be quite definite, and in order to obtain it absolutely the percentage of soil moisture near the point of maximum thermal movement must be increased by small amounts. This applies especially to the light sandy soil in which the sensitiveness appears to be more marked and the range more limited. If the increase in percentage of moisture content took place in this soil by 0.1% instead of 1.0% the maximum thermal translocation would probably have been as high as that of the other soils. It is possible, however, that the value obtained is about the upper limit for this soil and consequently for all soils of its type.

The diminution of the thermal translocation of water with decrease in moisture content from the point of thermal critical moisture content, might be anticipated, but the decrease of water movement with further increase of moisture content after the point of thermal critical moisture content, was not expected. Indeed, it was at first thought that the movement would be greater at the highest moisture contents because there would also occur a gravitational movement. When soils containing as high as 35.0 and 30.0 per cent of moisture as did the Clyde silt loam and the clay respectively and when one-half of their column is kept at 40° C. and the other at 0° C. for 8 hours, such expectation as the above is not at all unnatural. Instead, the water movement at these highest moisture contents is very low, and in descending order, and the cessation of diminution is not as yet reached. These results go to show then, in a most striking manner, that the soils possess a very great attraction for water, and that their requirements for water to satisfy their attractive forces before free movement of water can take place, are indeed high. Until the point is reached where gravitational movement occurs the moisture in the soil is held by a force of great magnitude.

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Now, the next question is how may this peculiar thermal translocation of water be explained? What are the causal agents which bring it about?

As already stated it is not entirely due to the surface tension and viscosity of the soil water; for if that were the case then the movement should have followed a different course. If the soil exerted no adhesive force for water than the amount of moisture moved from warm to cold column of soil should be the same for all moisture contents, providing the force of gravity is eliminated, for any particular amplitude of temperature. But since the soil does exert a strong adhesive force for water then the thermal motion of water should follow a straight line with rise in moisture content, for any given difference in temperature. Instead, the results plot into a parabola. Evidently, there must be another explanation for the phenomena.

The best explanation that is suggested appears to be founded upon the following four assumptions: (1)The soil possesses an attractive power for water and holds it with a great adhesive force; (2) these attractive and adhesive forces decrease with increase in temperature; (3) the surface tension or cohesive power of the liquid also diminishes with rise in temperature; and (4), the force due to the curvature of the water films between the soil grains which are known as capillary films, decreases with increase of water content.

All these four assumptions appear to be correct. The validity of the third and fourth is generally recognized and consequently need no further discussion. The validity of the first is also universally accepted; that the soil possesses an attractive power for water can hardly be denied; that the soil holds the water with a great adhesive force is evidenced by the great difficulty experienced in attempting to separate the one from the other. Indeed, this adhesive force is so great that no method as yet has been devised either to execute a complete separation of the two components, or to measure with any degree of precision its magnitude. The researches of Lagergren[1], Young[2], and Lord Rayleigh[3] indicate, however, that this force may be an order of magnitude from 6,000 to 25,000 atmospheres. As the water content increases this force decreases.

The great attractive and adhesive forces which the soil exerts for water are further illustrated by the researches of Briggs and McLane on the moisture equivalent and those of Briggs and Shantz[4] on the wilting coefficient of plants[5]. By whirling wetted soils in a rapidly revolving centrifuge, fitted with a filtering device in the periphery, and developing a force equivalent on the average to 3,000 times the attraction of gravity, Briggs and McLane found that some clay soils would still contain about 50% of water. Biggs's and Shantz's studies on the wilting cœfficient of plants show that plants would wilt and die in clay soils even when the moisture content was still about 30%.

Of all the four assumptions the correctness of the third, namely, that the attractive and adhesive forces decrease with rise in temperature may be doubted by many and challenged by few; the theoretical and experi-

[1]Uber die beim Benetzen fein verteilter Körper auftretende Wärmetönung von Lagergren, Behang till K. SV. Ve-takakt., Handl., 24, afd, 11, No. 5, 1898.
[2]Hydrostatics and elementary hydrokinetics, G. M. Minchin, p. 311, 1892.
[3]On the theory of surface forces, by Lord Rayleigh, Phil. Mag. (5), 30, 285-298, 456-475, (1890).
[4]Bulletin 45, U. S. Bureau of Soils.
[5]Bulletin 230, U. S. Bureau of Plant Industry.

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mental evidences, however, are overwhelmingly in its favor. According to the law of kinetic energy the attractive and adhesive forces of solids for liquids, and gases or vapors, should decrease with rise in temperature. The investigations upon the absorption of gases and vapors at different temperatures show such to be the case. The work of de Sausure[6] and Von Dobeneck[7] upon the absorption of gas by different solid materials, and the researches of Knop[8] and Ammon[9] upon the absorption of water vapor by soil, seem to show conclusively that the absorptive power of diverse solid materials for gases and water vapor, decreases with increase in temperature. The only evidence which is contrary to the above is that obtained by Hilgard[10] on the absorption of water by dry soils from a saturated atmosphere. Hilgard's results show that the absorption of water vapor by soils increases with rise in temperature. The results obtained by the several investigators mentioned as well as new evidence which will subsequently be presented, tend to throw considerable doubt on the correctness of Hilgard's data. Hence, it can safely be asserted that the third assumption is correct.

Bearing these postulates in mind the phenomena of thermal water translocation observed may be explained as follows: The soil with lowest moisture content holds the water with a force of great magnitude. When the temperature of a column of this soil is uniform throughout the adhesive and attractive forces are at an equilibrium. When one half of this column of soil is heated to 40° C. and the other half to 0° C. this equilibrium is disturbed. The attractive and adhesive forces of the soil for water and the cohesive power or surface tension of the soil water are decreased in that portion of the soil column which is maintained at 40° C. and increased to a corresponding magnitude in that portion of the soil column which is kept at 0° C. The cold column, therefore, exerts a pull and draws water from the warm column in amount depending upon the quantity that the warm column of soil is willing to give up. Since the soil possesses a great attraction for water, which attraction varies with the diverse classes of soil, and inasmuch as this attractive force is not satisfied at the low moisture content, the warm soil parts only with a small amount of its water. Hence, the amount of water moved from the warm column to the cold column of soil, is small. At the next higher moisture content the attractive power of the soil for water is further satisfied and the total water content is held with less force. When a column of this soil is kept at the same amplitudes of temperature as above, the decrease and increase of the adhesive and cohesive forces, due entirely to temperature, between the warm and cold columns of soil are equal in amount as in the soil with the lowest moisture content. Water, therefore, tends to move from the warm to the cold soil. Inasmuch, as the attraction of the soil has been further satisfied and the water films further thickened, the pull of the cold soil, due only to the attractive forces of the soil for water, is decreased, but the ease with which the warm soil gives up moisture is, on the other hand, increased. The result is that even though the total effective pull (which is composed of the increased surface tension of water, increased attractive and adhesive forces of soil for water, and the force of the curvature of the capillary films)

[6]Ann. Phys. Gilbert, 47, 113 (1814).
[7]Forsch. Agr. Phys., 15, 163 (1892).
[8]Cited by Johnson, How Crops Feed, pp. 161-162, (1870).
[9]Forsch. Agr. Phys., 2, 163 (1892).
[10]Soils, p. 198 (1912).

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of the cold soil with the high moisture content is less than that of the soil with low moisture content, the greater ease with which the warm soil with high water content parts with moisture enables the reduced affective pull to draw more water from the warm to the cold side. As the moisture content of the soil is continually increased its attractive power is satisfied and the curvature of the capillary films decreased, correspondingly; the total effective pull of the cold column of soil is continually decreased but the ease with which the warm column of soil gives up moisture is also continually increased, so that the thermal translocation of water is constantly increased with rise in moisture content. Finally, a degree of moisture content is reached in which the effective pull of the cold column of soil is able to extract the greatest amount of water from the warm column of soil. This degree of water content is the *thermal critical moisture content.* At this point the attractive power of the soil for water is considerably satisfied but far from being entirely appeased; the total effective pull of the cold column of soil is also considerably less than that of the preceding columns of soil, but the warm column yields water to this pull with such ease that there occurs a maximum thermal water translocation. Inasmuch as the water attractive power is different for the various kinds of soils, this thermal critical moisture content is necessarily different. After this thermal critical moisture content is reached the effective pull of the cold column of soil is further decreased with continued increase of moisture content; and although the willingness of the warm column of soil to part more readily with moisture is also increased, yet the pull of the cold column of soil is not sufficiently strong to draw it, and consequently the thermal movement of water commences to decrease; and continues to diminish very regularly and gradually with continued increase in moisture content. When the highest percentage of water is reached the warm soil is very willing to part with a very large amount of water but since the effective pull of the cold soil is reduced almost to minimum, only a small amount of moisture is drawn from the former to the latter.

The degree of moisture of the different soils could not be further increased on account of the difficulty of sifting them, and consequently it cannot be stated with certainty whether the thermal movement of water would become zero at a still higher moisture content. From the theoretical point of view, however, it should not become zero because the pull due to the surface tension of water alone is not affected by increase of moisture content, but remains constant. The portion of pulling force which is decreased constantly with rise in moisture content is that pertaining to the attractive power of soil for water, and to the curvature of the capillary film. At or near the point of saturation the pulling power due to these two factors is probably zero; at this point the soil may be considered to be passive. Any thermal movement of water that takes place at or near the point of saturation is to be attributed to the surface tension of the soil water. If this assumption is correct, and if the percentage of moisture moved at the highest moisture contents employed, is to be considered as a measure of the amount of thermal translocation due to surface tension of water alone, it will be found that the quantity due to this force, is very small indeed. As will be seen from the experimental data, the percentage of moisture moved at both amplitudes of temperature is reduced to an insignificant value at the highest moisture contents.

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The foregoing exposition as to the cause and mechanism of the phenomena of thermal water translocation, will probably be made more clear by figure 3. This diagramatic representation, however, by no means pictures the real cause and mechanism, absolutely and accurately, but it will serve, it is believed, to make what has already been said more clear.

Let the ordinate represent the effective pull of the cold column of soil, and the willingness of the warm column of soil to part with water, at

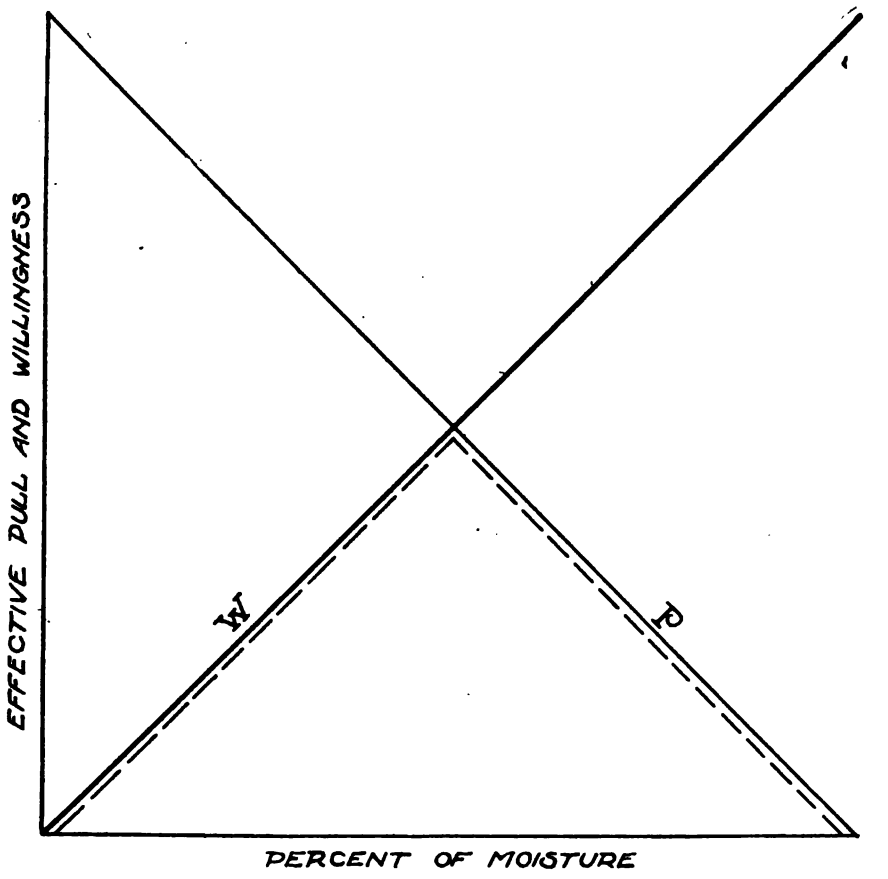


FIG. 3. CURVE ILLUSTRATING THE CAUSE AND MECHANISM OF THE THERMAL MOVEMENT OF WATER IN SOILS OF UNIFORM MOISTURE CONTENT.

different moisture content; and the abscissa, the different percentages of water contained by the soil. By plotting the effective pull and willingness against the moisture content it will be seen that the effective pull decreases and the willingness increases, with rise in moisture content. At the point where the two lines cross probably occurs the maximum thermal translocation of water. After this point of intersection, the willingness of the warm soil to give up water is large, but since the effective pull is being reduced to minimum, the water is not moved. If now a parabola is drawn along the lines WP with its maximum value at



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the point of intersection, then this theoretical curve agrees almost perfectly with the real one in figure 2.

The serious fault with the above illustration is that the total effective pull tends to become zero, and, theoretically, this should not be the case, because while the pull due to the attractive power of the soil for water, and to the curvature of the capillary films will ultimately become zero, the pull due to the increased surface tension of the soil water should not become zero, but should remain the same for all moisture contents. Hence, the above diagram illustrates more correctly only the thermal translocation of the water as due to all the other forces except to the surface tension of water.

The next important question to consider is the mode and amount of thermal translocation of water in field soils as suggested by the foregoing laboratory experimental data. Under field conditions the soil moisture exists practically always in a gradient form. As the water content tends to decrease upwards from the water level, the forces due to the curvature of the capillary films, and to the attractive power of the soil for water, increase correspondingly, consequently the pull is upward. The soil temperature also exists in a gradient form, but this reverses itself diurnally and therefore modifies these pulling forces. During the day the temperature at the upper depths is higher than that below, the attractive and adhesive forces of the soil for water, and the surface tension of water, are decreased, so that the total upward effective pull is diminished correspondingly. Inasmuch as the temperature below is less than that above, the effective pull due only to the increased attractive and adhesive forces of the soil for water and to the surface tension of the soil water, should occasion a downward movement of moisture. Since, however, the water attractive forces of the soil below are more satisfied than those of the soil above, the downward pull, due only to the attraction, adhesion and surface tension as increased by a lower temperature, is very small in comparison with the upward pull. Hence, during the day, the moisture movement is upward. During the night, nearly all of the above forces act in a parallel direction and favor an upward movement. *Hence, the thermal movement of capillary moisture in soils is always upward and never downward.*

The extent to which moisture will move during the night from the warmer soil below to the colder soil above will depend, (1) upon the soil temperature gradient, that is, upon the difference in temperature of the various adjacent depths, and (2) upon the gradient or amount of moisture content at the various depths. In the preceding series of experiments the temperature amplitudes of 20° and 40° C. were employed. In nature, however, so large and sharp variations in temperature between adjacent depths never occur during the night; (they do occur, however, at the upper depths between day and night). Soil temperature investigations which are being conducted at this Station show that in the early morning when the temperature gradient is most marked, the temperature of the bare mineral soils increases, sometimes in the summer and fall at the average rate of about 2° or 3° C. for each inch depth down to about 4 inches and then this rate becomes less. In cropped soils, where the temperature remains more constant, this rate of increase of temperature with depth is still less. *Hence, the amount of thermal translocation of water that would occur during a single night would be very small.* On the other hand, the maximum thermal trans-

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location of water obtained in the preceding series of experiments was procured from column of soil with uniform moisture content. As will be shown subsequently there is no doubt whatever, but that this maximum thermal translocation of water in the various soils would have been far greater if the moisture content of the cold column of soil was less than that of the warm column of soil. In nature, as already mentioned, the moisture exists in a gradient form and consequently the movement of water is upward, and the forces of the factors which cause this upward movement are increased during the night. *Hence, while the amount of thermal translocation of water during a single night in bare soils under field conditions may not be as great as that obtained in the foregoing series of experiments, yet it will be quite appreciable; and since the process is repeated, the sum of water translocation of all the nights during the vegetative season, will probably be considerable.*

The moisture content at which the maximum thermal translocation of water occurs, or what has been designated as the thermal critical moisture content, is very significant and needs further consideration. It would be of very great interest to know, for instance, what the thickness of the water film around the particles is at this degree of moisture. This thickness could be calculated if all the soil grains were solid and spherical. The particles of the soils used, however,—and these are the commoner types of agricultural soils—are neither spherical nor solid. Nearly all the particles in agricultural soils can be said to be irregular in shape; some of them are solid and enveloped with a colloidal coating; others are compound aggregates or "crumbs" and are porous; and still others, mainly of the peat nature, are of a sponge structure, and are necessarily porous. The particles of a soil or soils may be classified under two categories: (1) particles which are solid and have only an external surface, and (2) particles which are partly or wholly porous and possess both an external and internal surface. In the case of the solid and cleaned surface particles, the water film is spread over the surface, but in the case of the solid particles coated with colloids, or the mineral flocules and the organic particles, the film of water envelopes, theoretically, their whole external surface, and also water permeates their internal surface. The single solid mineral grains, which may compose the compound particles, may be cemented together in a way analogous to that found in a piece of sandstone, in which case the water exists only in the interstices and not as a complete film around each particle. Furthermore, whether the soil grains are solid or spherical, or compound and porous, the water film is not uniform in thickness over the entire inner surface of the soil mass, but thickens more at the capillary angles between the particles.

In view of these considerations, therefore, it was considered useless to attempt to compute the thickness of the film as many investigators have done. *Furthermore, in view of the nature of the soil particles as discussed above, it does not appear strictly proper to define the capillary water in the soil as many writers do as a thin film overspreading the particles and thickened into a waist-like form at their points of contact.* Hence, a new definition of capillary water is needed.

If we are to accept the theory which has been used to explain the foregoing phenomena of thermal translocation of water that the soil possesses a very great attraction for water, that this attractive force is

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different for various soils, that it decreases with a rise in moisture content, and that it is completely satisfied at a rather high moisture content, then our present views concerning the movement of capillary water in *moist soils* needs modification. The present theory regarding the capillary movement of water consists of an analogy from the rise of water in capillary tubes. The interstitial spaces of a soil mass are considered as forming channels analogous to capillary tubes, and are often designated as bundles of capillary tubes. The capillary water is believed to exist as surface films around the particles, and as capillary films in the capillary spaces between the particles, and its movement is said to depend entirely upon the curvature of the capillary films. When a dry soil, for instance, is well moistened and brought to equilibrium, the water films are thick and the curvature of the capillary films small, and there will be no further capillary attraction of water if this soil is brought in contact with water. If now this soil is allowed to dry at the top the surface films become thinner and the force of the capillary films increases in direct ratio with their degree of curvature, hence, there will be a pull of water from the thicker surface films and less curved capillary films below, towards the surface.

It is obvious that this theory of capillary movement of water attributes the whole cause of the capillary motion of water in a moist soil to the curvature of the capillary films between the particles, and considers the moist soils as being passive, inactive, and exerting no influence whatever upon the motion of water. Indeed, Briggs[11] and Lapham in trying to explain the differences in capillary action in dry and moist soils, make the following statement: "In a moist soil, however, we have quite another condition. A film of the liquid covers all the surfaces of the soil grains. Since this film, once established, is maintained in a saturated atmosphere, it follows that the soil-air and solid-liquid surfaces forces no longer play any part in the capillary movement, which is produced entirely by the air-liquid surface force and is opposed only by the weight of the liquid column." In view of this general belief Briggs, as well as other investigators, has tried to alter the properties of the soil water, by increasing its surface tension, etc., with the object in view of increasing its capillary action.

If it were true that as long as a thin film of water is maintained in a damp or slightly moist soil, the soil material itself exerts no longer any influence upon the movement of capillary water, then the preceding theory might be true. But we have seen in postulate (1) page 14, that the soils, and especially those rich in colloidal material, possess a very great attractive power for water, that this attractive power is satisfied only at a rather high moisture content, that as long as it is not satisfied the soils will continue to take up water, and that they hold the water with a force of great magnitude. *In view of the considerations presented in this postulate and in view of the fact that the preceding thermal movement of water appears to be largely controlled by the attractive forces of the soil for water, it seems wrong to consider the soil material in moist condition as a static, passive, inactive and irresponsive skeleton upon which the liquid plays its role. The soil material, in moist condition, short of saturation, is dynamic and not static in respect to moisture movement. Hence, the capillary movement of water should*

[11] U. S. Dept. of Agr. Bureau of Soils Bulletin No. 19, p. 28 (1902).

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*not be attributed entirely to the forces exerted by the curvature of the capillary films, but also to the forces exerted by the unsatisfied attractive power of the soil for water.* When a moist soil, therefore, begins to lose water at the surface two effects are produced: (1) the attractive forces of the soil for water are increased, and (2) the curvature of the capillary films is increased, both of these effects exert a pull on the moist soil below and tend to draw water to the surface. As to which one of these two forces exerts the greatest pull, it is impossible to say, because there is no way of measuring them. It is certain, however, that the force resulting from the attractive power of the soil for water must be very considerable, and probably it is the predominant of the two.

It might be argued that the preceding phenomena of thermal translocation of water could be explained entirely by the film theory, without having to resort to the conception of the attractive forces of the soil. Such a contention, however, cannot be maintained, first because it cannot be conceived that the tension of the capillary films is operative and effective at such high moisture contents employed, and secondly, because the fact remains nevertheless that the soil exerts a pull due to its attractive forces for water as has been abundantly proved. Furthermore, if it is maintained that the attractive forces of the soil for water are satisfied as soon as the soil is merely dampened, then why should the soil hold additional large amounts of water with such a great force that it is impossible to extract it with mechanical means? It seems reasonable, therefore, to believe that if the soil holds large amounts of water with a great force, it should attract or absorb it with a force of equal magnitude.

### MOVEMENT OF MOISTURE FROM MOIST AND WARM COLUMN TO DRY AND COLD COLUMN OF SOIL WITH AN AIR SPACE BETWEEN THE TWO COLUMNS.

In the preceding section the thermal translocation of water was considered as occuring as water film phenomena. There is still another way in which this thermal mobility of moisture might take place, this is by evaporization and condensation of soil water from a point of high temperature to a point of low temperature. It is well known that water undergoes a transformation into the vapor state by the application of heat, and the quantity of liquid vaporized increases with rise in temperature. One of the remarkable characteristics of aqueous vapor is its sensitiveness to heat, changing from gaseous to liquid state and vice versa with very small variations in temperature. As an excellent paradigm of this latter fact may be cited the relative humidity of the air at different temperatures.

Since the temperature gradient of the soil reverses itself during the night, that is, it increases with depth, it is believed that there is a rising of vapor or moist air from the warmer soil below to the colder soil above where the moisture is condensed. As a manifest proof of this theory the morning dew is cited. It is concluded, therefore, that a large part of the water movement in soils is due to this process.

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There appear to exist no direct experimental data as to whether or not there really is a translocation of moisture in soil at night, due to upward movement of the moist warm air, and the condensation of its moisture at the cold soil above. Practically all our present knowledge upon the subject consists of theoretical deductions and from practical observations.

With the object of obtaining experimental evidence upon the subject the following investigation was performed: Into brass tubes 8 inches long and 1½ inches in diameter was placed moist soil at one end and dry soil at the other, and the two columns separated by an air space. This air space was ¼ inch in height and 1½ inches in diameter and was produced by placing between the two columns of soil a ring of cork the two sides of which were closed with wire gauze which acted as supports of the two soils and prevented their particles from coming in contact. The tubes were then placed horizontally in the boxes shown in figure 1. That part of the tubes which contained the moist soil was kept at 20° and 40° C., and the part which contained the dry soil was maintained at 0° C. The experiment was allowed to run about 8 hours. If during this period the dry and cold soil gained any moisture it obtained it by the condensation of vapor which was produced at the warm and moist soil. Since the dry soil possesses a high absorbtive power for water it was assumed that it abstracted the vapor from the air space and that this air space was thus prevented from attaining an equilibrium. There were five different classes of soils used, quartz sand, Miami light sandy loam, Miami silt loam, Clyde silt loam, and Miami clay. The moisture contents employed for each soil were three low, medium, and high. The results obtained are presented in table 3. The percentage of moisture moved from the warm and moist column of soil to the cold and dry column of soil represents the difference between the percentages of moisture found in the dry soil at the beginning and end of the experiment.

TABLE 3.—PERCENTAGE OF MOISTURE MOVED FROM WARM AND MOIST COLUMN OF SOIL TO COLD AND DRY COLUMN OF SOIL WITH AN AIR SPACE BETWEEN THE TWO COLUMNS.

| Kind and temperature of soil. | Percentage of moisture. | | |
|---|---|---|---|
| **Quartz sand:** | | | |
| Moisture in moist column | 2.90 | 6.83 | 13.52 |
| Movement from moist column at 20°C., to dry column at 0°C | 0.051 | 0.046 | 0.048 |
| Movement from moist column at 40°C., to dry column at 0°C | 0.286 | 0.280 | 0.294 |
| **Sandy loam:** | | | |
| Moisture in moist column | 7.23 | 10.27 | 15.82 |
| Movement from moist column at 20°C., to dry column at 0°C | 0.0238 | 0.0313 | 0.0246 |
| Movement from moist column at 40°C., to dry column at 0°C | 0.211 | 0.253 | 0.223 |
| **Silt loam:** | | | |
| Moisture in moist column | 9.16 | 14.52 | 16.40 |
| Movement from moist column at 20°C., to dry column at 0°C | 0.024 | 0.033 | 0.0273 |
| Movement from moist column at 40°C., to dry column at 0°C | 0.278 | 0.273 | 0.288 |
| **Clyde silt loam:** | | | |
| Moisture in moist column | 9.85 | 15.51 | 23.39 |
| Movement from moist column at 20°C., to dry column at 0°C | 0.028 | 0.031 | 0.040 |
| Movement from moist column at 40°C., to dry column at 0°C | 0.16 | 0.22 | 0.28 |
| **Clay:** | | | |
| Moisture in moist column | 10.77 | 15.36 | 20.35 |
| Movement from moist column at 20°C., to dry column at 0°C | 0.08 | 0.06 | 0.09 |
| Movement from moist column at 40°C., to dry column at 0°C | 0.18 | 0.36 | 0.26 |

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The above results show the most surprising fact that the amount of moisture moved from the moist and warm column of soil to the dry and cold column of soil by vapor is very insignificant indeed. It will be seen that at the temperature amplitude of 40° C. the quantity of moisture moved is only about 0.25%, and at the amplitude of 20° C. the value is only about 0.035%. In comparison with the results of table 2 where it is shown that the maximum thermal movement of water at the thermal critical moisture content, when the soil mass is continuous, runs as high as 3.68% in some cases, then the above values, due only to vapor movement and condensation, are extremely insignificant.

*From these results then it is safe to conclude that the thermal movement of moisture due to distillation is practically negligible, even at such high amplitudes of temperature of 20° and 40° C. which never exist during the night at the different adjacent depths in the soil, nor during such a long continuous period as 8 hours.* This conclusion is indirectly substantiated by the studies of Buckingham[12] on the loss of soil moisture by direct evaporation from points below the surface. By exposing a surface of water or moist soil to evaporation into a confined space which was in communication with the outside air through a column of soil, Buckingham found that the actual mean rate of loss of water through diffusion of water vapor through soils in still air, was very small.

Another noteworthy fact to be noticed in the foregoing experimental data is that the amount of distillation from moist and warm to the dry and cold column of soil is the same for all moisture contents. This might have been anticipated since the amount of water vaporized depends principally upon the temperature and is not governed by the amount of water present. On the other hand, if the amount of water present in the soil is extremely small, the water is held by the soil grains with an attraction of great magnitude, causing a lowering of the vapor pressure of the absorbed water film and thereby producing a diminution in the rate of evaporation. Perhaps the water contained in the soil with the lowest moisture content was above the point where this lowering of vapor pressure occurs, and consequently the partial pressure of the vapor in the air space in this soil was the same as in the air space of the soil with the greater moisture contents. Furthermore, the values are so small as to be within the experimental error, and the method of moisture determination may not be sufficiently sensitive and accurate to show any decreased evaporation by the soils with the lowest moisture content.

In undertaking and performing the foregoing series of experiments it was taken for granted that there really is an upward movement of moist air during the night from the warmer soil below to the colder soil at the surface, where its vapor is condensed. This theory seems to be now very widely accepted as already stated. The formation of the dew is attributed by many writers almost entirely to this thermal movement of vapor. Thus, in discussing the subject Hilgard[13] states ..... "dew is formed from vapor rising from the warmer soil into a colder atmosphere, and condensed on the most strongly heat-radiating surfaces near the ground, such as grass, leaves both green and dry, wood and other objects first encountering the rising vapor." Farther on he says: "The fact that dew is most commonly derived from the soil could have been foreseen from the other fact, long ascertained and known, that dur-

[12]U. S. Dept. of Agr., Bureau of Soils Bulletin No. 38 (1907).
[13]Soils, p. 307 (1912).

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ing the night the soil is as a rule warmer than the air above." Other writers, such as Ramann[14], etc., claim in substance the identical belief.

But really, is there a rising of vapor or warm moist air from the warm soil below to the cold soil above? And is the source of water of the dew due to this soil vapor? During the day the soil receives its heat at the upper surface and its temperature rises. The heat is conducted downward and the temperature of the various depths of the soil increases correspondingly. The temperature at the surface continues to rise until a maximum is reached and then commences to decrease. As the temperature rises and moves downward the soil air expands, and as the volume of the pore space remains constant, it is expelled into the atmosphere. The pressure of the soil air at the different depths tends to be the same at any one time and equal to the atmospheric pressure, provided the communications are ideal. When the temperature at the surface soil is at maximum it is generally many degrees higher than that of the air above, amounting sometimes to 30° C. In fact the air temperature decreases, in calm and clear weather, with increase in height at the adiabatic rate of approximately 0.9° C. per 300 feet. When the temperature of the surface soil and of the air is highest the atmospheric pressure also tends to be at its minimum, so that the air escapes from the soil with greater facility. After the surface soil attains its maximum temperature and then begins to cool, its air contracts, tends to produce a partial vacuum, and consequently draws air from the atmosphere, so its pressure will be in equilibrium with that of the latter. The fall of temperature is also conducted downward, and proceeds as a wave, and as it descends it causes a diminution in volume at the corresponding depths, and therefore produces an inward flow of air. This cold wave, however, is preceded by the maximum temperature wave which, as it proceeds downward, causes a further expansion of air, which goes to make up for the decreased volume of air caused by the cold wave following immediately after. The difference in temperature, however, of the soil at any depth immediately before and after the maximum temperature wave is reached is very small, as experiments at this Station show, and consequently the expansion and expulsion of air caused by the downward march of the maximum temperature wave is not very appreciable. Hence, as the cold wave proceeds downward and produces a decrease in volume of the soil air, the air that comes to make up for this decrease, so that an equilibrium of pressure will exist, is mainly from the outside atmosphere. After a certain depth is reached the maximum temperature wave entirely disappears, and there is no more upward expulsion or movement of air. From now on, as the temperature of the soil is further decreased and the volume of its air is diminished correspondingly, the current of flow of air into the soil is entirely from the outside atmosphere. This downward flow of air will continue until the soil temperature begins to rise again and the cycle recommences. When the minimum temperature of the surface soil is reached, it is as a rule, about the same or slightly higher, than that of the air immediately above. The temperature of the air at about this period increases with the height, in the same manner as the temperature of the soil increases with depth, which is just the opposite from what it is during the day. This increase instead of decrease of a

[14]Bodenkunde, p. 382 (1911).

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temperature at night with rise in elevation is called surface temperature inversion. At this minimum temperature the atmospheric pressure approaches its maximum, and the inward flow of air is thereby facilitated.

*All the foregoing facts lead to the enunciation of a general law that during the day, as the temperature rises, the soil air tends to flow outward into the atmosphere, and during the night, as the temperature falls, air from the atmosphere tends to flow inward into the soil.* This law diametrically opposes the prevalent theory that during the night there is an upward movement of moist warm air. The above law, however, seems to be borne out by logic and appears to be confirmed by experimental evidence subsequently to be presented. The prevalent theory, however, seems unreasonable. For instance, if it is admitted, which it must be, that the soil air escapes into the atmosphere during the day as the temperature rises, then where and when does the soil obtain its air if it continues to give up air even during the night? It might be argued that it is vapor that is rising to the surface and not air. That is inconceivable in the present case. It is true that distillation would occur if the amplitude of temperature were appreciable and constant, but it has been shown that the temperature of the whole column of soil decreases constantly, and that an air current from the cold atmosphere is drawn inward which tends to encounter and oppose any upward movement of vapor rising from any difference in temperature. Moreover, granting for sake of argument that there is a vapor rising from the warmer soil to the colder soil at the surface, the amount would be extremely small to account for the great quantity of dew commonly noted, because the temperature amplitudes of the soil at different depths at night are never very great. In fact, during the spring months as the temperature of the lower depths continually rises and the trend of the air temperature is upward, the range of temperature between the surface and the lower depths say 4 inches, is small, usually amounting only to about 2 or 3° C. The greatest differences in temperature at the different depths in the morning occur in the fall when the trend of the air temperature is downward and the surface soil temperature continually falls. At this time the variation in temperature between the surface and six inches of the mineral soils may be as high as 8° C. but the variation between adjacent depths is only from about 0.5° to 2° C.

*The truth of the matter, however, seems to be that instead of vapor rising from the warmer soil below to the colder soil at the surface, vapor enters the soil from the atmosphere.* This is a natural conclusion from the law enunciated that during the day air is exhaled from the soil and during the night air is inhaled from the atmosphere. The amount of moisture that will thus enter the soil will depend upon the quantity of air inhaled and upon its absolute humidity, but as will be seen subsequently it is extremely small. The water may be abstracted by the dry soil at the surface as the air is drawn in or it may enter unaffected. Thus, it is possible that the moisture lost by the soil during the day *by the expulsion of its moist air* is partly, if not wholly, regained at night.

What is then the source of water of the dew? The greatest part of it comes from the lower layer of the atmosphere itself by condensation. Some of it comes from the leaves of trees and plants. And a certain amount comes from the soil by capillary and thermal capillary action as set forth previously.

According to the foregoing consideration, therefore, the notion that

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"dew is formed from the vapor rising from the warmer soil into a colder atmosphere" is wrong, and those who proposed and adhere to this theory seem to be laboring under misapprehension of facts.

## MOVEMENT OF MOISTURE FROM MOIST AND WARM COLUMN TO DRY AND COLD COLUMN OF SOIL, AND FROM MOIST AND COLD COLUMN TO DRY AND WARM COLUMN OF SOIL.

The soil moisture under field conditions exists during the warm period of the year, nearly always in a gradient form. During a long drought the upper surface even dries out, either by its own accord or aided by artificial means. This layer of dry soil formed at the surface is known as mulch. To this mulch is ascribed the important function of conserving the moisture in the soil by its ability to reduce evaporation of water at the surface. It accomplishes this conservation of moisture, it is claimed, by producing a change or break in the capillary connections between itself and the moist soil below.

Since, on account of the kinetic energy, the absorptive and adhesive forces of the solid substances decrease with rise in temperature, the interesting question arose whether the dry mulch with an excessively high temperature would absorb moisture from a moist soil with low temperature, even when the capillary connections were ideal. The desire to secure information upon this important and exceedingly interesting point led to the execution of the following experiments: Brass tubes described in the preceding sections, were filled one-half with dry soil and the other half with moist soil, and the two columns were separated only by a circular piece of cheese-cloth in order to facilitate separation of the two columns for moisture movement determinations. The tubes were then inserted in the boxes shown in figure 1, and that portion of the tubes containing the moist soil was kept at 20° and 40° C, and that part which held the dry soil was maintained at 0° C. In another set of tubes these temperatures were reversed. The soils employed were the same as those previously described, namely: quartz sand, light and heavy Miami sandy loam, Miami silt loam, Clyde silt loam and Miami clay. There were three different moisture contents used for each soil, designated as, low, medium, and high. The duration of all experiments was about 8 hours. The numerical data obtained are shown in table 4 below. The accompanying figure 3 represents these same data graphically. Each soil has two charts, the one to the left is for the temperature amplitude of 40° C., and the one to the right is for the temperature range of 20° C. The abscissas, in every case, represent percentage of moisture content, and the ordinates, percentage of water moved either from the moist and warm column to the dry and cold column of soil, or from the moist and cold column to the dry and warm column of soil. The upper curves of each chart represent the percentage of water movement that took place from the moist and warm soil to the dry and cold soil, and the lower curves show the movement of water that occurred from the moist and cold soil to the dry and warm soil. As in the preceding case, the percentage of mois-

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ture moved is based upon the difference in percentages of moisture contained in the dry soil at the beginning and end of the experiment.

TABLE 4.—PERCENTAGE OF MOISTURE MOVED FROM MOIST AND WARM COLUMN OF SOIL TO DRY AND COLD COLUMN OF SOIL, AND FROM MOIST AND COLD COLUMN OF SOIL TO DRY AND WARM COLUMN OF SOIL.

| | | Percentage of moisture. | | |
|---|---|---|---|---|
| Moisture in moist column of soil | | 1.85 | 5.30 | 8.75 |
| Quartz sand. | Movement from moist column at 20°C., to dry column at 0°C | 0.0746 | 0.0879 | 0.1129 |
| | Movement from moist column at 0°C., to dry column at 20°C | 0.0105 | 0.02131 | 0.03912 |
| | Movement from moist column at 40°C., to dry column at 0°C | 0.2048 | 0.2210 | 0.2376 |
| | Movement from moist column at 0°C., to dry column at 40°C | 0.0121 | 0.0160 | 0.01522 |
| Moisture in moist column of soil | | 6.497 | 10.141 | 14.17 |
| Light sandy loam. | Movement from moist column at 20°C., to dry column at 0°C | 0.345 | 0.550 | 0.820 |
| | Movement from moist column at 0°C., to dry column at 20°C | 0.061 | 0.163 | 0.448 |
| | Movement from moist column at 40°C., to dry column at 0°C | 0.779 | 1.18 | 1.496 |
| | Movement from moist column at 0°C., to dry column at 40°C | 0.000 | 0.08 | 0.235 |
| Moisture in moist column of soil | | 9.906 | 12.30 | 14.695 |
| Heavy sandy loam. | Movement from moist column at 20°C., to dry column at 0°C | 0.592 | 0.569 | 0.863 |
| | Movement from moist column at 0°C., to dry column at 20°C | 0.215 | 0.211 | 0.445 |
| | Movement from moist column at 40°C., to dry column at 0°C | 0.937 | 1.094 | 1.309 |
| | Movement from moist column at 0°C., to dry column at 40°C | 0.168 | 0.169 | 0.150 |
| Moisture in moist column of soil | | 10.89 | 17.88 | 18.67 |
| Silt loam. | Movement from moist column at 20°C., to dry column at 0°C | 0.687 | 0.844 | 0.989 |
| | Movement from moist column at 0°C., to dry column at 20°C | 0.411 | 0.461 | 0.529 |
| | Movement from moist column at 40°C., to dry column at 0°C | 1.413 | 1.942 | 2.038 |
| | Movement from moist column at 0°C., to dry column at 40°C | 0.347 | 0.445 | 0.438 |
| Moisture in moist column of soil | | 15.349 | 25.086 | 36.18 |
| Clyde silt loam. | Movement from moist column at 20°C., to dry column at 0°C | 0.429 | 0.662 | 0.962 |
| | Movement from moist column at 0°C., to dry column at 20°C | 0.100 | 0.606 | 0.900 |
| | Movement from moist column at 40°C., to dry column at 0°C | 0.814 | 1.554 | 2.046 |
| | Movement from moist column at 0°C., to dry column at 40°C | 0.042 | 0.594 | 0.852 |
| Moisture in moist column of soil | | 17.05 | 21.88 | 23.29 |
| Clay. | Movement from moist column at 20°C., to dry column at 0°C | 0.514 | 0.653 | 0.923 |
| | Movement from moist column at 0°C., to dry column at 20°C | 0.436 | 0.502 | 0.796 |
| | Movement from moist column at 40°C., to dry column at 0°C | 1.180 | 1.482 | 1.552 |
| | Movement from moist column at 0°C., to dry column at 40°C | 0.380 | 0.850 | 0.873 |

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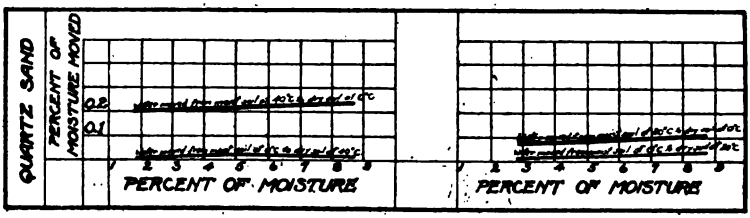


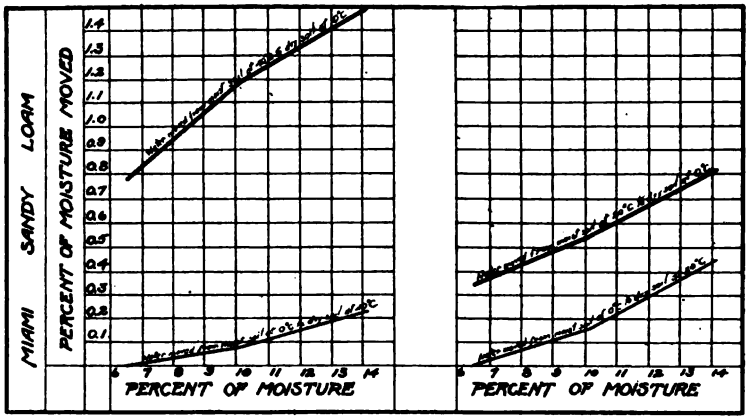


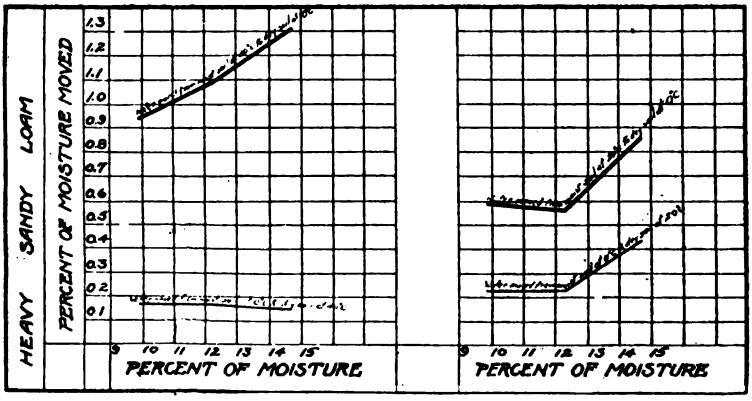


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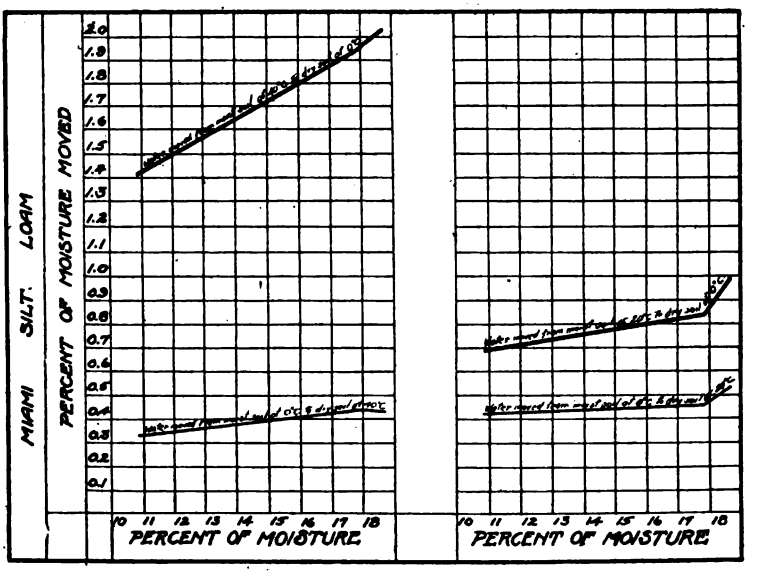


FIG. 4. CURVES SHOWING MOISTURE MOVEMENT FROM MOIST AND WARM COLUMN OF SOIL TO DRY AND COLD COLUMN OF SOIL; AND FROM MOIST AND COLD TO DRY AND WARM COLUMN OF SOIL.

Considering first the numerical values showing the amount of water moved from the moist and warm column of soil to the dry and cold column of soil, which are graphically represented by the upper curve of each chart, it will be seen (1) that this amount is nearly twice as great in the temperature amplitude of 40° as in 20° C., (2) that it is somewhat greater in soils with higher than with lower colloidal content, and (3) that it increases with the rise in moisture content.

By comparing these results with those obtained with column of soils of uniform moisture content, some very striking contrasts are revealed. The previous results show, for instance, that the maximum thermal motion of water occurs at a definite but comparatively low moisture content, and that the value amounts in some cases over 3.50 per cent. The above data, show, however, that the maximum movement of water from the moist and warm column to the dry and cold column of soil, takes place at the highest water content, and that in the majority of cases the percentage of this maximum water translocation is only one-half as great as in the former case.

These apparent differences seem to be easily explainable. The increase of water movement from moist and warm soil to dry and cold soil with rise in water content is natural, and only goes to prove that the water is held by the soil with low moisture content, with a great force, and consequently it cannot be extracted readily and extensively by a greater abstracting force. When the attractive forces of the soil for water are satisfied, and the thickness of the surface and capillary films is increased, then greater quantities of water will be removed by the same abstracting force. The smaller thermal water movement which occurs in the moist

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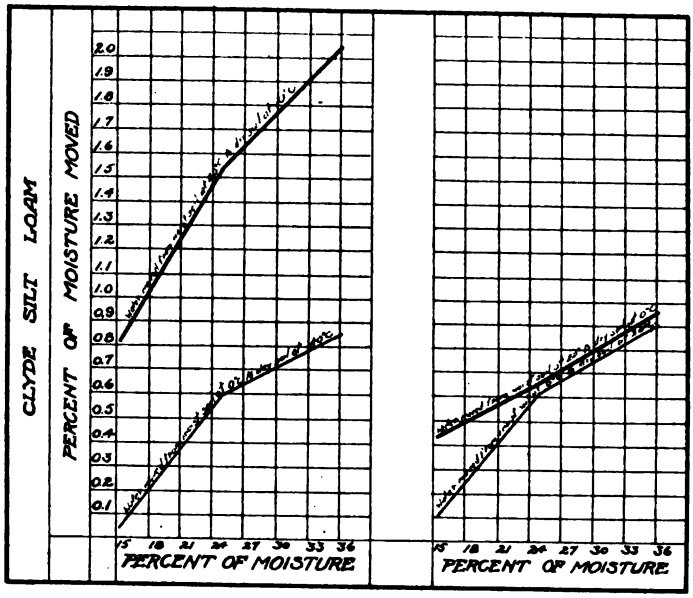


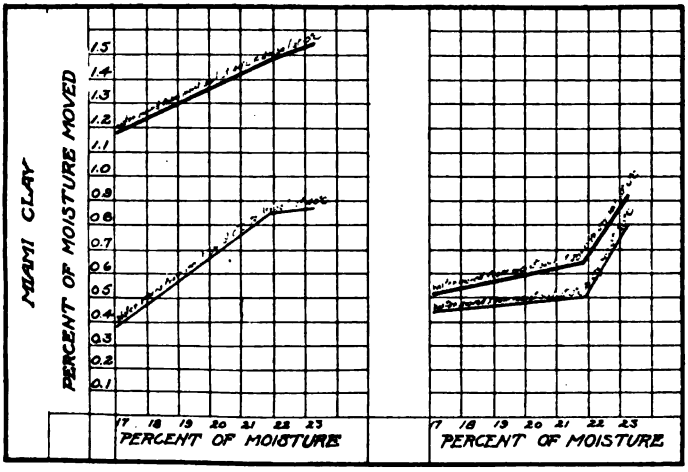


FIG. 4. CURVES SHOWING MOISTURE MOVEMENT FROM MOIST AND WARM COLUMN OF SOIL TO DRY AND COLD COLUMN OF SOIL; AND FROM MOIST AND COLD TO DRY AND WARM COLUMN OF SOIL.

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and dry soil than in the soil of uniform moisture content, is due mainly to the cheese-cloth which is placed between the dry and moist columns of soil. Although this cheese-cloth was very thin and had large perforations, yet it prevented the two columns from forming a complete and perfect contact, and consequently the dry soil had to absorb water directly through the cheese-cloth, as well as from the soil.

Another factor which would seem to impede the rate of water movement from moist and warm to dry and cold column of soil is the resistance which the dry soils offer to wetting, due to the air film surrounding the particles and to any oily substance that might be present. The influence of this factor, however, must be extremely small, if any, because when these soils were slightly damped the amount of water moved was generally less or about the same as before. *The common belief that water moves more rapidly in damp than in dry soils is generally exaggerated. When a soil is damped to eliminate the factor of resistance to wetting its absorptive power for water is decreased correspondingly so that one factor tends to counterbalance the other, and at the end the results are about the same.* Moreover the soils which stubbornly resist wetting are not very common.

From the practical standpoint the results of the second part of the present investigation are probably far more important than those of the first part just disscussed. *These results show the remarkable fact that when the dry soil is kept at 20° and 40° C. and the moist soil at 0° C. the dry soil takes up very little if any, water from the moist soil, and that this quantity of water, absorbed decreases with rise in temperature.* As will be seen from the figures the percentage of moisture absorbed by the dry soil at 20° C, is in all cases greater than that absorbed at 40° C. At both amplitudes of temperature, the percentage taken up increases with the colloidal content in the soil, which is natural.

Obviously then, the temperature has a tremendous influence upon the absorptive power of soils for water. This is what might be expected from the laws of kinetic energy. According to this law the energy or motion of the molecules increases with temperature, and consequently the adhesive and absorptive forces of the solid matter for liquids or gases, decreases. These results then, tend to confirm postulate 2 page 14 that the attractive forces of the soil for water decrease with rise in temperature.

*The foregoing experimental results and theoretical consideration suggest very strongly that the efficiency of the soil mulches in conserving moisture in the soil is not dependent solely upon their thickness and degree of capillary discontinuity between themselves and the moist soil below, but also upon their temperature.* It is well known that the temperature of the surface soils during sun insolation is many degrees higher than that of the air immediately above. In some parts of the world, where the sky is clear and the sun insolation very intense, the surface soil may attain a temperature about 40° C. higher than that of the air about 4 feet from the ground. Even at this Station the surface soil temperature of the mineral soils and especially of the light sandy soils, is very often approximately 15° C. higher than that of the air above. From the surface downward the soil temperature decreases, but in the upper 1 or 2 inches the diminution is far more rapid than at the lower depths, amounting sometimes, and in certain soils, over 10° C. for each

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inch depth. When the surface soil is disturbed and a mulch is formed its heat conductivity is decreased, and the high temperature attained at the surface is not all conducted downward but is compelled to accumulate on the dry mulch and then is radiated back into space. The difference in temperature between the mulch and the moist soil below is sometimes as high as 10° C. at this Station. At the arid regions this difference must be far greater. This excessively greater temperature of the dry mulch diminishes the adhesive and absorptive forces of the dry soil so that its capacity and intensity to withdraw water from the moist soil below are either entirely prohibited or greatly reduced. The result is that the water is saved from direct evaporation. On the other hand, during the night the soil temperature reverses itself and becomes lowest at the surface and increases with the depth, but its difference between the mulch and moist soil is generally not as great during night as during the sun insolation. Since the attractive and adhesive force of the dry soil and the surface tension of the soil water are increased by the low temperature, the tendency of the soil moisture is to move upwards very energetically. To what extent this movement occurs cannot be stated with certainty because the moisture, not very far below the mulch, is held with a great force and is given up with great reluctancy, unless moisture moves from further depth below and satisfies the absorptive power, and thickens the surface and capillary films.

Furthermore, the amount of water moved will depend upon the temperature gradient, that is, upon the range of temperature between the surface and lower depths. As already stated, this temperature gradient at night between adjacent depths is always small but is most marked during the summer and fall and least during the spring. Any water, however, that the mulch pulls up during the night is certain of being evaporated during the day. *May it not be then that an appreciable amount of water is lost from the soil in this manner?*

Temperature not only tends to conserve moisture in the soil after the mulch is formed but also aids and hastens the formation of this mulch. It has been seen that as the temperature of the moist soil at the upper depth increases the surface tension of the soil water and the adhesive and absorptive forces of the soil, decrease. The upward pulling force, therefore, is diminished, and the water is not brought up with sufficient rapidity to keep the upper layers moist, so that a mulch is formed at the top. The diminution of the surface tension of the soil water at or near the surface is very large during the sun insolation, and far greater than the increase during the night, because during the sun insolation the soil absorbs heat from the sun very rapidly and since the soil is a poor conductor of heat, the heat is allowed to accumulate at the surface and raise its temperature far above that of the next layers.

The foregoing considerations have been deduced from the experimental data, and from the laws of kinetic energy of matter, surface tension of liquids, etc., in their relation to temperature. It is now of great importance as well as of high interest to know if these deductions can be verified experimentally. The type of experiment which the writer probably would have performed to test out whether or not the temperature does tend to conserve moisture in the soil, has fortunately been performed by Buckingham[15] for another purpose. In his studies on the

[15]U. S. Dept. of Agr., Bureau of Soils, Bulletin No. 38 (1907).

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loss of water under arid and humid conditions, Buckingham endeavored to imitate these two conditions in the laboratory. He placed soil in cylinders 48 inches long and 2½ inches in diameter, and provided each cylinder with side tubes at the bottom for the introduction of water. He allowed, by means of an electrical fan, a current of air to be blown over the top surface of the soils. For the arid conditions this current of air was heated, without changing its absolute humidity, to a temperature of about 50° to 60° F. above the room temperature. To imitate also the high surface temperature of soils under the strong sunshine of arid climates, the top inch and a half of the cylinders under the hot air was heated, by heating coils surrounding the cylinders, to about the same temperature as the hot air. The breeze of about 3 miles per hour, was kept going all the time. The heating current was turned on for six hours a day except on Sunday and holidays. For the humid conditions the soils were placed under the current of air at room temperature. Buckingham performed a number of experiments bearing upon this subject and the results he obtained are qualitatively about the same for all of them. The following diagram shows a typical set of results.

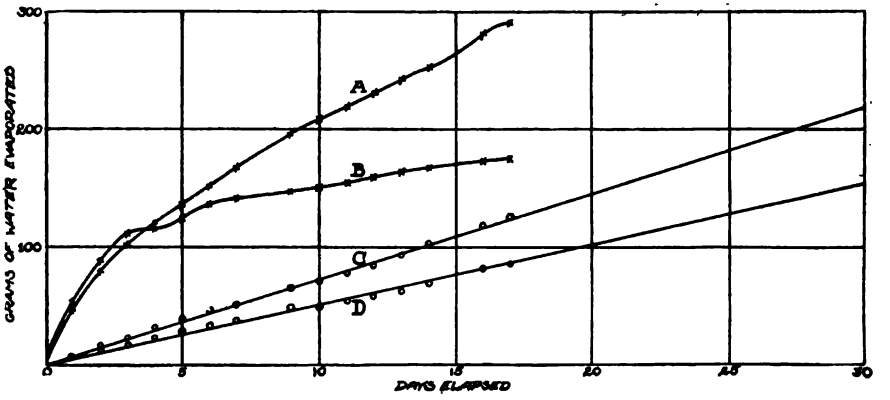


FIG. 5. CURVE SHOWING EVAPORATION OF WATER FROM PODUNK FINE SANDY LOAM WITH TAP WATER; A, SOIL UNDER HUMID CONDITIONS; B, SOIL UNDER ARID CONDITIONS; C, WATER UNDER ARID CONDITIONS; D, WATER UNDER HUMID CONDITIONS. (AFTER BUCKINGHAM.)

An examination of the above figure shows that the loss of water from the soil under arid conditions is much more rapid at first but after about 4 days have elapsed the rate of loss is less under arid than under humid conditions, and continue to be so throughout the duration of the experiment. The rate of evaporation from the soils for the last ten days is 11.2 inches of rain per year under arid conditions and 51.6 inches of rain per year under humid conditions.

Buckingham explains these results under the supposition that a mulch was formed on the soil kept under arid conditions, more rapidly than on the soil kept under humid conditions, and the mulch prevented rapid loss of water from the former. This explanation is correct, of course, in so far as it represents the result of the mulch, but how this mulch was formed and how it was capable of accomplishing this result, it fails to



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explain correctly. In the opinion of the writer *the above results offer an excellent proof that temperature aids and hastens the formation of a mulch, and tends to conserve the soil moisture in the manner previously set forth.*

This is a remarkable paradox indeed, that temperature which causes the loss of water should also cause its conservation.

## THERMO-OSMOSE IN SOILS.

In the course of the foregoing studies on thermal movement of moisture in soils, the question arose: What would happen if on two sides of a soil membrane is placed water of an unequal temperature? Would there be a diffusion of water? And if so would the hot water diffuse towards the cold, or vice versa? The difference in temperature between the two faces of the membrane is analogous to the difference in concentration of solution. If any movement of water occurred in either direction it might be classed under the category of thermo-osmotic phenomena, probably similar to those observed by Lippmann[16] in the case of the gelatine, and golden beaters skin where cold water moved towards the hot. In such an event the soil would act as a semi-permeable membrane in the same manner as in solutions of different concentrations as shown by Lynde[17] and Robinson.[18] It was at first thought that certain of the foregoing data on thermal translocation of water might be attributed to thermo-osmotic phenomena.

Considerable time was expended in endeavoring to devise a method to attack the problem. After several trials the apparatus shown in figure 6 was devised and finally adopted. It consists of a brass tube 11 inches long and 1½ inches in diameter having 4 one-half inch holes, two cap nuts C, and two compressing plungers P. The holes were 1 inch apart at the two ends of the tube, and 3½ inches at the center. The soil whose thermo-osmose or thermo diffusion was to be investigated was placed in the middle of the tube and pressed together by the two compressing plungers. The outer ends of the plungers were loosely connected to the cap nuts and by screwing the latter to the tube the soil in the middle could be pressed to any desired degree. The heads of the plungers were fitted to the tubes tightly and were perforated so as to allow free communication between the soil and water. To prevent the soil from being forced out through these perforations a very fine gauze was inserted on the inner side of each plunger which came in contact with the soil. For maintaining a difference in temperature at the opposite compartments of the soil membrane a wooden box with a partition in the center was employed. The tube was inserted through a hole in the partition and the soil membrane came under this hole and extended equally in both directions. After the two compartments of the wooden box were made water tight either by paraffin or by a compound called "chlorine putty," the two enclosures of the soil membrane were filled with water, and in the inner two holes of the tube were placed two straight glass tubes, and in the

[16]Comptes rendus 1907, p. 104.
[17]Journal of American Society of Agronomy, Vol. 4, p. 108 (1912).
[18]Results obtained at the Michigan Experiment Station but not as yet published.

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outer two holes, two horizontally bent glass tubes of very small diameter. The straight vertical tubes served the purpose of adding water to the compartments and bringing the level of the water to a standard position. On the horizontally bent tubes was intended to read any thermal diffusion of water. The vertical tubes were either left open or closed.

The possibility of thermo-osmose was studied in kaolin and in two

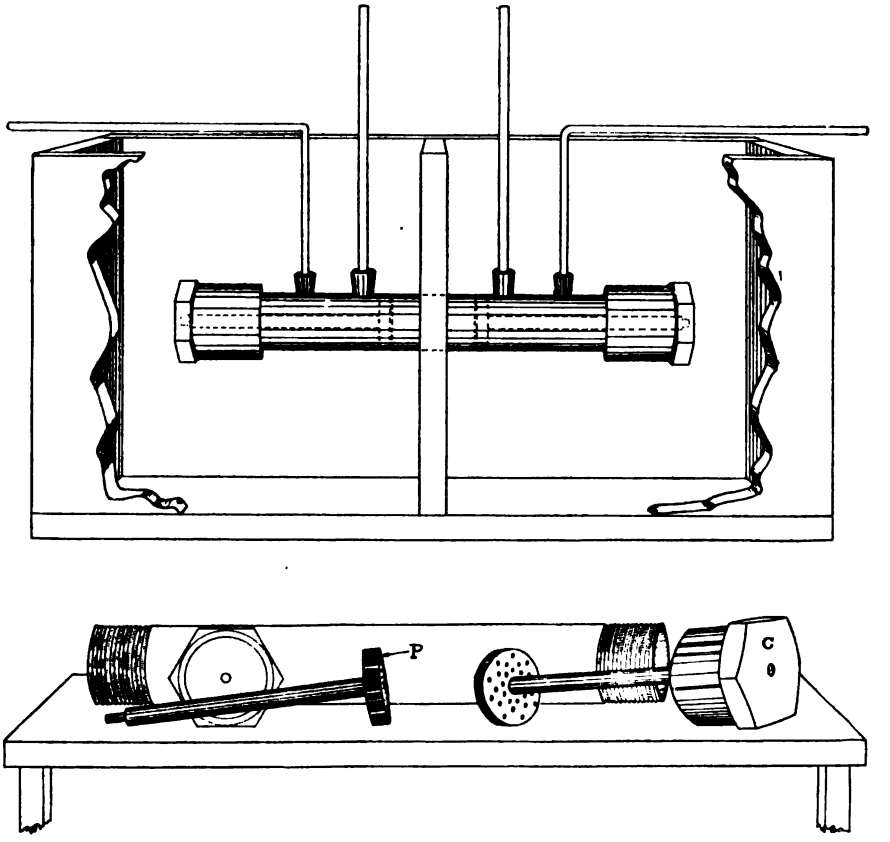


FIG. 6. APPARATUS FOR STUDYING THERMO-OSMOTIC PHENOMENA IN SOILS.

different kinds of clay, of different thickness of membrane. The temperature amplitudes employed were 0°-20°, 0°-40°, 0°-60° C. In a large number of trials no thermo-osmose was observed: no movement of water occurred in either direction.

The failure of obtaining any results led to the conclusion that either the method was not sufficiently perfected, or that there is no thermo-osmotic phenomena in soils. In the opinion of the writer the latter conclusion is more probable.

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## EFFECT OF TEMPERATURE ON THE PERCOLATION OF WATER IN SOILS.

As shown in table 1, the surface tension and viscosity of water decrease with rise in temperature. From these data it is to be expected that the rate of flow of water in soils should increase in direct ratio with temperature. In summer time the rate of percolation should be greater than in winter, before freezing.

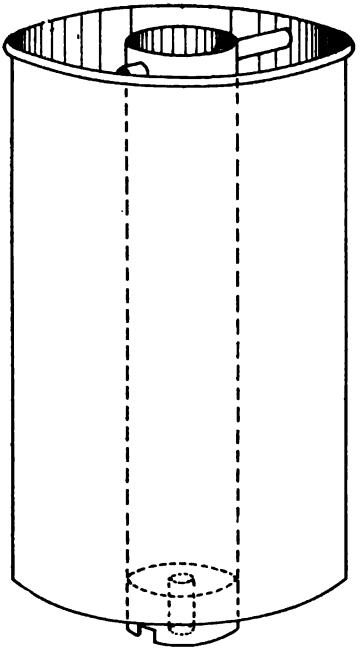

FIG. 7. APPARATUS FOR DETERMINING THE EFFECT OF TEMPERATURE ON THE RATE OF FLOW OF WATER IN SOILS, ALSO THE EFFECT OF TEMPERATURE ON THE WATER-HOLDING CAPACITY OF SOILS.

The only and often cited experiment upon this subject is that of King, in which he attempted to study the influence of temperature upon the rate of percolation of water through a sandy soil only. King found that a rise of temperature of from 9° to 24° C. increased the rate of percolation 50 per cent. Briggs, through calculation, came to the conclusion that these results are precisely those which might have been predicted from the known diminution of viscosity of water with rise in temperature.

Since the subject is of considerable importance and has received really no study, a research of it was undertaken. The method of procedure consisted in keeping a column of soil at a definite temperature and allowing

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water of the same temperature to percolate. The soil column was contained in a brass tube 14 inches long, and 3 inches in diameter. The soil was placed in the tubes in air dry condition, compacted lightly, and then water allowed to flow through it for three or four days in order to give it a more uniform structure before it was used for experimental purposes. About 2 inches of space was left at the top for a constant head of water pressure. Surrounding the soil tube was a cylindrical compartment 14 inches long, and 10 inches in diameter, and soldered to the soil tube at the bottom as shown in figure 7. In this outer compartment was contained the water at the desired temperature. A channel at the upper part of the soil tube connected the head of water pressure with the level of the outside mass of water. As the percolation in all the soils, except in the sand, is slow, the constancy of the head of water pressure was maintained with no difficulty. The temperature of the water in the outer compartment, and consequently that which flowed through the soil, was changed and maintained to any desired degree, by the addition of either hot water or ice. There are electrical devices which could have been used for this purpose, but it was not considered expedient and necessary, as the above method answered the purpose almost equally well. The soil was allowed to remain and water to percolate through it at any particular temperature for two hours before readings were taken of the velocity of percolation. Inasmuch as the volume of the water in the outer compartment was large and the vessel well insulated on the outside, the temperature remained fairly constant for long periods of time. The temperatures employed were 0°, 10°, 20°, 30° 40°, and 50° C. The classes of soils employed were sand, sandy loam, silt loam, clay loam, clay, and muck. The results obtained are detailed in table 5. They give grams of water percolated during a period of 30 minutes. Figure 8 represents these data in a graphical form.

TABLE 5.—EFFECT OF TEMPERATURE ON THE PERCOLATION OF WATER IN SOILS.

| Soil. | Grams of water percolated in 30 minutes. | | | | | |
|---|---|---|---|---|---|---|
| | 0° C. | 10° C. | 20° C. | 30° C. | 40° C. | 50° C. |
| Sand | 1215.00 | 1533.60 | 1903.50 | 2496.90 | 2854.80 | 3688.50 |
| Sandy loam | 17.84 | 20.92 | 24.24 | 26.26 | 26.61 | 23.51 |
| Silt loam | 5.04 | 5.86 | 6.57 | 6.56 | 7.48 | 5.23 |
| Clay loam | 12.17 | 13.85 | 15.99 | 17.85 | 17.26 | 13.96 |
| Clay | 20.10 | 22.35 | 24.48 | 24.91 | 23.69 | 17.16 |
| Muck | 6.57 | 7.03 | 8.61 | 9.98 | 9.39 | 9.06 |

An examination of these data at once reveals the fact that the rate of percolation of water does not increase in all cases with rise in temperature. On the contrary, with exception of sand, in all the other soils the velocity of flow increases up to a certain temperature and then diminishes again with continued ascent of temperature. The temperature at which the maximum rate of percolation occurs and then commences to descend, is about 30° C. In the case of sand, however, the velocity of flow increases regularly and rapidly with rise in temperature.

Obviously then, the prevalent *a priori* reasoning that the rate of percolation of water in soils increases with increase of temperature is neither

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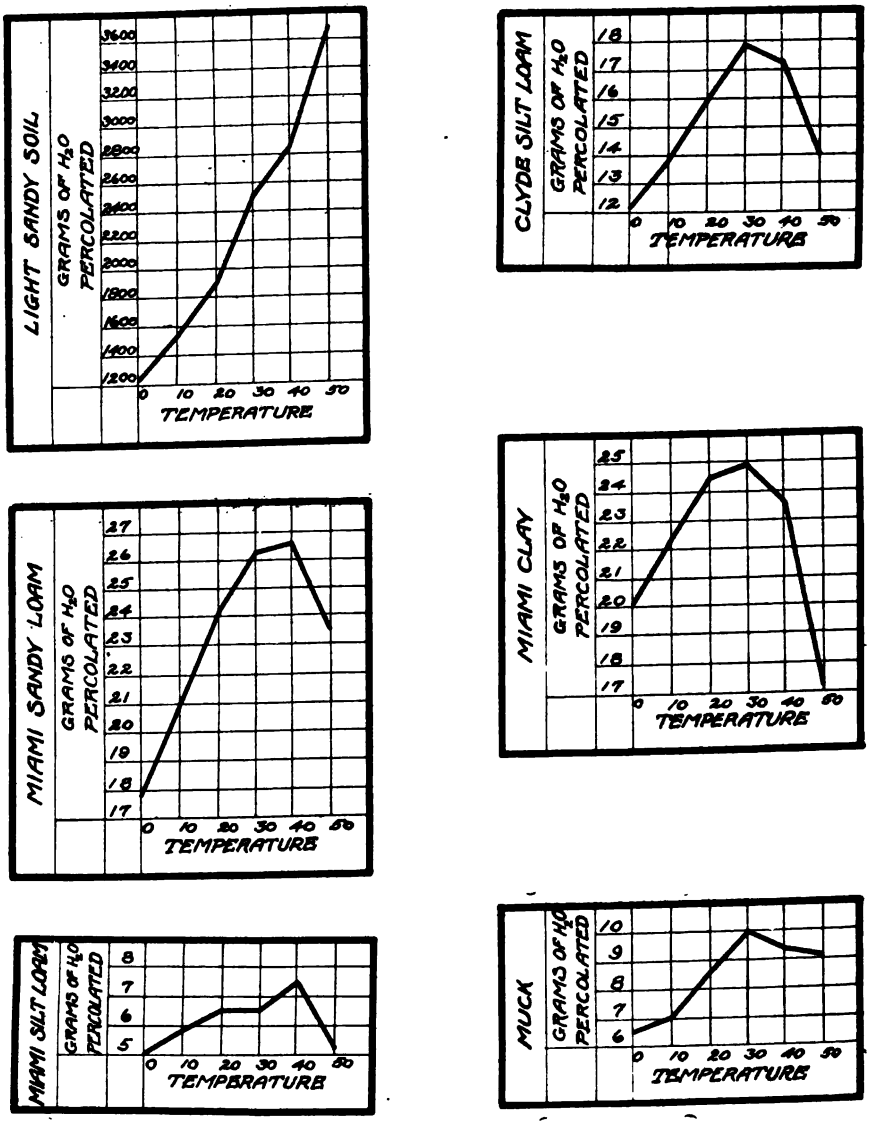


FIG. 8. CURVES SHOWING EFFECT OF TEMPERATURE ON THE PERCOLATION OF WATER IN SOILS.

entirely confirmed nor justified. Evidently, there appears to be some other factor or factors which are influenced more predominately by temperature than the viscosity of water, and succeed, partially or completely, in overpowering the effects of the latter. These opposing factors are to be found (1) in the swelling of the colloidal material present in the soil, and (2) in change in structure of the soil mass, with increase in temperature.

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The extensive studies on the subject of colloids have shown that soils contain substance of this nature, and that some classes of soil possess them more abundantly than others. In what structural form they exist in the soil is not as yet definitely known; but evidences seem to indicate very strongly that a part of them at least exists as a gel coating around the solid particles, and another part as individual gel aggregates. Now, it is also known that colloidal substances swell when they absorb water, and that this property of swelling increases with temperature. Their increase in volume at high temperature is probably due, (1) to their inherent constitution, and (2) to the expansion of water they contain.

If soils, therefore, containing colloidal substances are placed in firm and inflexible tubes, such as those used in the present research, in order to oppose any horizontal thrust, and the temperature of these soils is varied, the rate of flow of water through them, will be governed by the viscosity of water, the structure of the soil mass, and the colloidal content of the soil. At about 4° C. the last two factors, and especially the last, favor rapid percolation, but the first factor tends to reduce it. As the temperature rises, the viscosity of water diminishes rapidly and favors the flow of water, but the colloidal material swells and tends to reduce the rate, by filling up the pores through which the water flows. This swelling may not be considerable at the lower temperatures, and allows the reduced viscosity to predominate, so that the velocity of percolation increases with rise in temperature. When a certain temperature is reached, however, the increase in volume, due to swelling of the colloids and expansion of water attains a considerable magnitude, and since the volume of the vessel remains constant, the mass of soil is subjected to a strain: some rearrangement of the particles takes place; many of the pores are closed up, and the rate of percolation commences to decrease. At this temperature, therefore, the factor of swelling predominates over the decreased internal friction of the liquid. With a further increase in temperature this factor of swelling and the consequent closing up of the soil interstices, is augmented. The total result, will be, therefore, just what the experimental data really show. On the other hand, as the soil mass is maintained under a constant strain at the higher temperature, there may occur some radical change in the structure of the soil mass which will favor a high rate of percolation. Such changes were observed in some of the experiments.

In a sandy soil, however, the conditions are different. Here, there are no colloidal substances to swell and close up the pores, and consequently the rate of percolation follows more closely the law of viscosity. This rate, however, is modified by a change in the structure that takes place as the temperature rises. This change in structure in sand, seems to favor a more rapid flow of water. The abnormal velocity of percolation noted in this soil is due to the internal alteration in structure. That a change occurs in structure by varying the temperature is further confirmed by the following observation: When the rate of passage of water was determined say at 20° C. and then at 50° C. and the temperature was brought to 20° C. again, the two readings at 20° C. were not at all the same.

It thus appears that the unexpected trend of the results is explainable by the swelling of the colloidal material, and by the change in structure in the soil mass, with rise in temperature.

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The practical question now rises: Would identical results be obtained under natural conditions? This will depend to a large extent upon the structure and composition of the soil. If the soil is compact and contains large amounts of colloidal material the swelling of the latter probably may predominate and cause a decrease in the rate of percolation. If the same soil, however, is loose, and has many crevices, worm holes, etc., the decreased viscosity may predominate and increase the flow of water. On the other hand, it must be remembered that the temperature under field conditions exists practically always in a gradient form, while in the present research it was the same throughout the soil column.

From studies on the flow of water in soils, various investigators have attempted to express the relation of the soil to the movement of water through it, quantitatively. To accomplish this they have assumed that the porous soil is composed of bundles of capillary tubes, and that the velocity of flow of liquid will consequently conform to Poiseuille's formula, which is:

$$v = \frac{\pi}{8} \cdot \frac{ghst}{n} \cdot \frac{r^4}{l}.$$

when $v$ = volume of liquid;
and $s$ = density of liquid;
$r$ = radius of capillary;
$n$ = viscosity of liquid;
$l$ = length of capillary;
$g$ = gravitational constant;
$h$ = head of liquid pressure;

Such an assumption, however, is practically futile. In the first place, Poiseuille's formula was deduced from the ascertained rate of flow of liquid through straight tubes of approximately uniform diameter. The supposed bundles of capillary tubes in the soil are irregular in area, length, direction, and shape, consequently the formula is inapplicable. In the second place, the foregoing research shows that the soil material is dynamic and not static, and that temperature affects its physical constitution so greatly that the velocity of flow of water through it is entirely different from what might be expected from the known physical laws. Hence, it was considered useless to attempt to apply Poiseuille's formula to the foregoing experimental data.

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## EFFECT OF TEMPERATURE ON THE RETENTION OF WATER BY SOILS.

Since the amount of water retained by soils is believed to depend to a considerable extent upon the surface tension of the soil water, and inasmuch as we have seen that the surface tension of water is reduced by increase in temperature, it was decided to conduct an investigation to obtain numerical values of these relations. This research was facilitated by the fact that the same soils of the last section could be used. After the studies on percolation were completed these soils were brought to the temperature of melting ice and allowed to remain at this temperature for about 24 hours to drain. Their temperature then was raised to 50° C. by increments of 10° C., and any water that dripped down during a definite period at any particular temperature was caught and weighed. Preliminary trials showed that during a period of two hours the soils allowed to drain practically all the water that would drain at any one of the temperatures employed. In fact, at the higher temperatures, the soils ceased draining even before the completion of two hours. Throughout this investigation, therefore, the limit of two hours was used for all temperatures and for all soils. Table 6 and the accompanying figure 9 show the results obtained. The table contains also the percentage of water drained and thereby lost, at the different temperatures, based upon the dry weight of the soil.

The results show that in the case of the sandy loam, silt loam, clay loam, clay and muck the amount of water drained increases regularly and rather rapidly with increase in temperature. In the case of the sand, however, the quantity drained increases up to the temperature of 30° C. and then commences to diminish with further rise in temperature. The total quantity drained is about the same in the former soils, and about three times greater than in the latter soil.

The order of these results complies, in a general way, with what might have been expected, but whether the magnitude of the values, which is rather appreciable, is correct, cannot positively be asserted, because the relation of soil to water and other factors, complicate the problem. According to the figures presented in table 1, the surface tension of water decreases at the rate of about 0.2 per cent per degree Centigrade, so that for every 5° C. the rate decreases about 1 per cent. From this it would appear that the decrease in the water holding capacity of the soils follows the law, but not closely. It is certain, however, that the above quantities of water drained are not wholly due to the decrease in the surface tension of the soil water, but also to two other factors. These are (1) the expansion of the air in the interstices, and (2) the expansion of the soil mass, and consequently to the squeezing out of water. As the water leaves the soil by drainage at the temperature of melting ice, its space is replaced by air. When the temperature of the soil is raised this air, some of which is imprisoned, expands, and produces a sudden pressure throughout the soil mass and forces out or expels some of the free water which accumulates at the lower end of the tube, due to the greater attraction of gravity. As a proof of this may be cited the fact that the

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TABLE 6.—EFFECT OF TEMPERATURE ON THE RETENTION OF WATER BY SOILS.

| Soil. | Wt. of soil in grams. | Grams of water drained in 2 hours. | | | | | | | Percentage of water drained in 2 hours. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0° C. | 10° C. | 20° C. | 30° C. | 40° C. | 50° C. | Total. | 10° C. | 20° C. | 30° C. | 40° C. | 50° C. | Total. |
| Sand | 2031 | 0 0 | 3.41 | 5 21 | 6.89 | 4.21 | 3 29 | 23.01 | 0.1679 | 0.2565 | 0.3393 | 0.2073 | 0.1620 | 1.1330 |
| Sandy loam | 1842 | 0 0 | 6.10 | 8.20 | 13.70 | 21 63 | 22.38 | 72.01 | 0.3312 | 0.4452 | 0.7437 | 1.174 | 1.250 | 3.944 |
| Silt loam | 1750 | 0.0 | 7.25 | 10 25 | 11.45 | 13.72 | 17.66 | 60 33 | 0.4143 | 0.5857 | 0.6543 | 0.784 | 1.009 | 3.4473 |
| Clay loam | 1370 | 0 0 | 6.30 | 9.81 | 13.59 | 17.79 | 19 86 | 67.35 | 0 4599 | 0.7160 | 0.9920 | 1 299 | 1.450 | 4.9169 |
| Clay | 1333 | 0.0 | 5 42 | 8 42 | 10 69 | 13.37 | 21.88 | 59.78 | 0.4066 | 0.6316 | 0 8019 | 1.003 | 1.641 | 4.484 |
| Muck | 676 | 0 0 | 7 2 | 10 00 | 12.50 | 19.54 | 20.90 | 70.14 | 1.065 | 1.479 | 1.849 | 2.891 | 3.092 | 10.376 |

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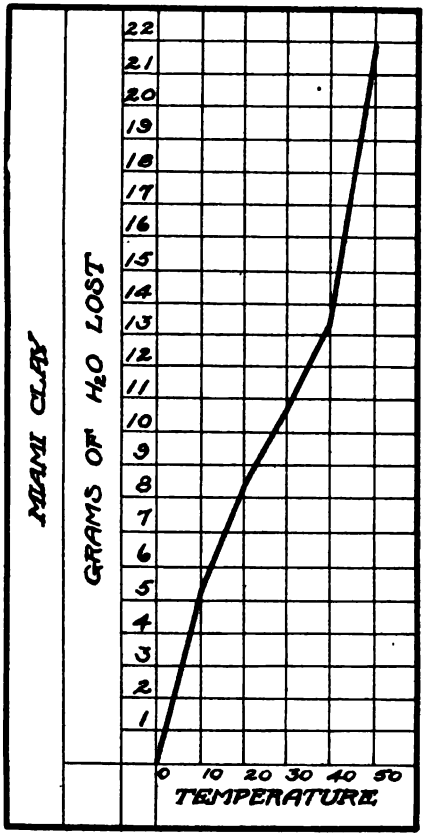


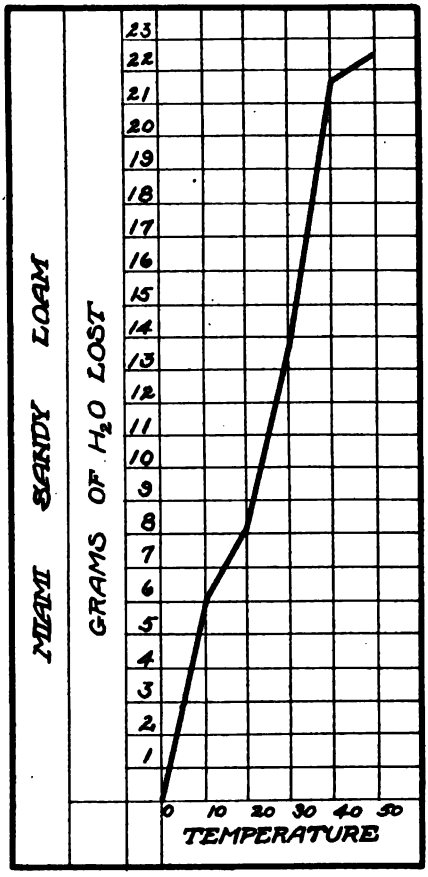


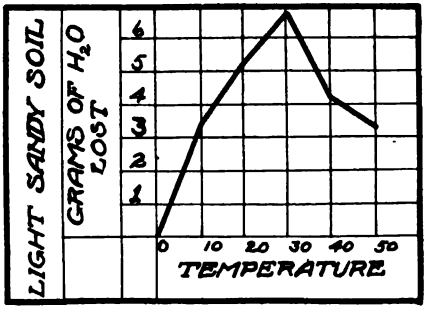


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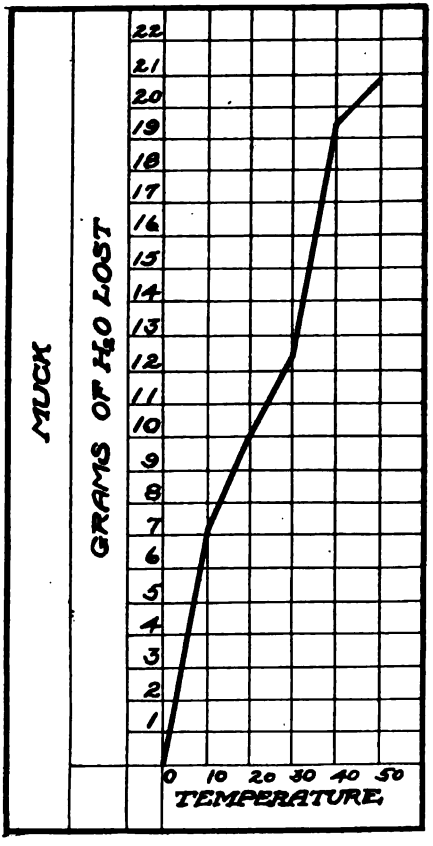


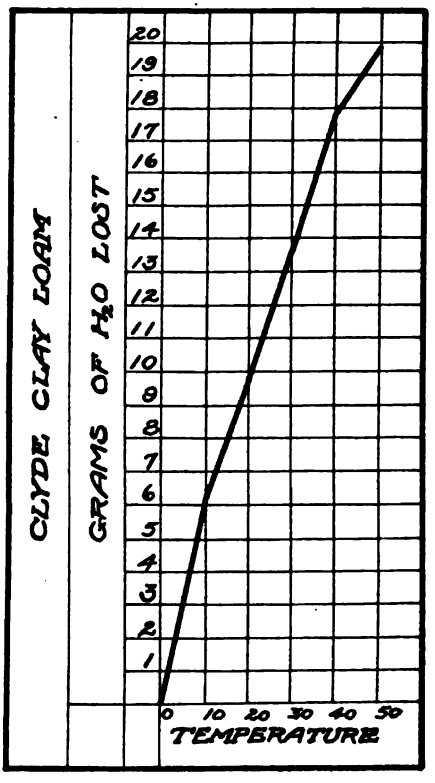


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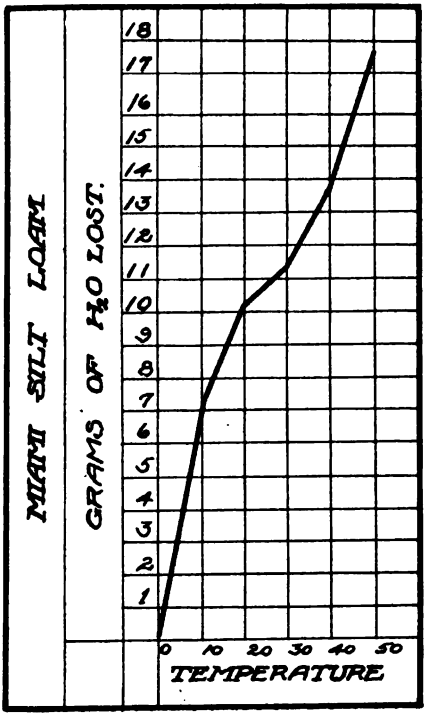


FIG. 9. CURVES SHOWING EFFECT OF TEMPERATURE ON THE RETENTION OF WATER BY SOILS.

greater portion of the water drained at the various temperatures, occurred in the first few minutes when really the soil mass had not as yet acquired to any appreciable degree the external temperature. Furthermore, if the soils were kept say at 50° C. for a considerable length of time and the dripping of water had completely ceased the latter would recommence almost instantly if the temperature was raised even 2 degrees higher. This observation seems to offer the real explanation as to the cause of the diurnal fluctuation of ground water in shallow wells as observed by King[19], and which has been erroneously attributed by many writers to the diurnal change of the surface tension of the soil moisture. There was probably air imprisoned within the soil between the surface and the water level which contracted during the night and expanded during the day and thus caused fluctuations in the ground water.

In the case of the soils with large colloidal content some water is actually squeezed out at the maximum temperatures employed, due to expansion and swelling of the colloidal material. During preliminary tests it was observed, for instance, that if peat and Clyde loam were in the tubes in a rather compact form, water would be forced to the top at the beginning, when the temperature was raised to 50° C.

[19]U. S. Dept. of Agr., Bul. 5, Weather Bureau, pp. 59-61.

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*A portion of the water that left the soil at the various temperatures should be attributed to the decreased adhesive power of the soil for water. It is not proper to consider the soil mass itself, as has been done heretofore, as a static and passive skeleton, and as being unaffected by, and irresponsive to temperature, and as playing no part in the capillary movement of water when it is moist. Indeed, the physical properties of the solid soil are affected by temperature as well as those of the liquid, for both classes of matter obey the law of kinetic energy of matter. It is wrong to speak then of the water-holding power of a soil being decreased by rise in temperature because the surface tension of its water is decreased; or that water is pulled upward in a moist soil because only of the curvature of the capillary films.*

In view of these considerations, it might be concluded that the diminution of the water holding capacity of a soil due solely to the decreased surface tension of the soil water by temperature is insignificant.

## EFFECT OF TEMPERATURE ON THE RATE OF FLOW OF AIR IN SOILS.

Unlike liquids, the viscosity of gases increases with rise in temperature. The velocity of flow of air in soils, therefore, with rise of temperature, should diminish correspondingly. The experiments of Ammon[20] and Wollney[21] have confirmed this conclusion. Ammon has also shown that the actual and calculated results agree. Both of these investigators, however, obtained their results under too abnormal and unnatural conditions, in that they used only dry powdered soils. The foregoing investigation on the velocity of flow of water through soils at the higher temperatures, gave occasion to suspect that the passage of air in dry soils may not be the same in moist soils either in order or magnitude. For this reason, the research presented herewith was undertaken.

The method of procedure consisted of drawing air through a moist column of soil at different temperatures by means of a small tank aspirator. The column of soil was contained in a tube, shown in figure 9, which is 8 inches long, and 8 inches in diameter, and has a small opening at the bottom for forming connections with the aspirator. This soil tube was surrounded by a circular compartment which served as a temperature bath. The soil column was about 5.7 inches high. In order to obtain as uniform conditions of structure and compactness among the different soils as possible, they were placed in the tube in air dry condition, slightly tapped, and water allowed to percolate through them for several days. Following this treatment they were subjected to an alternate drying, wetting, freezing, and thawing. These processes tended to give them a textural and structural condition somewhat similar to that usually found in natural soils under field conditions. The soils were used for the experiment when they contained, what is considered, an average moisture content. As they lost their excess of water the colloidal types contracted in mass and left a space between the sides of the column and the inner wall of the tube. This space was filled with hot paraffin so that

[20]Forch, a. d. G. D. Agrik—Physik, Bd. 3, S. 209.
[21]Forch, a. d. G. D. Agrik—Physik, Bd. 16, S. 193-222.

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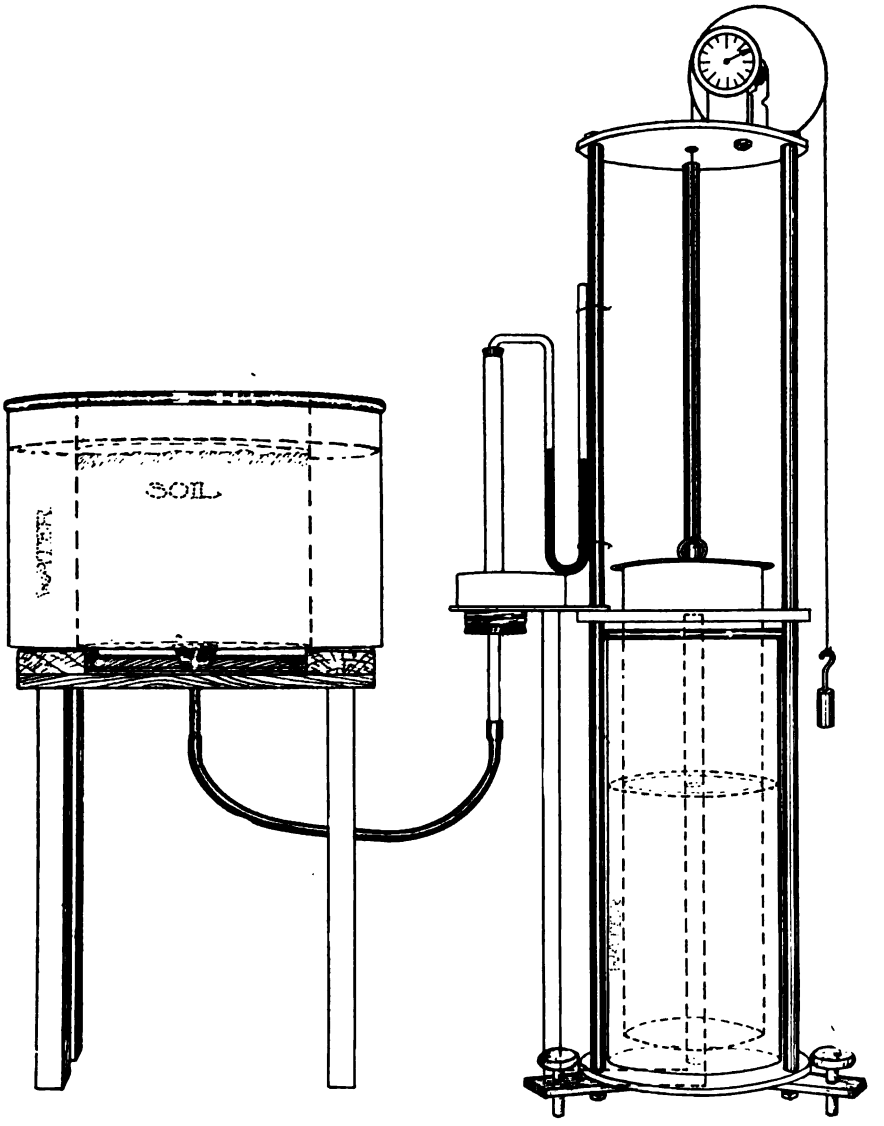


FIG. 10. APPARATUS FOR DETERMINING THE EFFECT OF TEMPERATURE ON THE RATE OF FLOW OF AIR IN SOILS.

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the air would be drawn only through the mass of the soil. The rate of passage of air was measured in quartz sand, sandy loam, silt loam, and clay of the Miami series, and Clyde silt loam and peat, at the temperatures of 0°, 10°, 20°, 30°, 40°, and 50° C. The soil column was kept at the same temperature from two to three hours before the transpiration measurements were taken.

The aspirator apparatus employed was similar to that of King's, with few modifications. This apparatus is shown also in figure 10. It consists of a sheet-galvanized iron can 15 inches high, and 5 inches in diameter, inverted over water into another can 14 inches high, and 6½ inches in diameter. The suction tube is ½ inch in diameter and 14½ inches high inside, and 16 inches high outside of the fixed can. The aspirator bell is attached to a fine brass wire which runs over a 6¼ inch grooved metallic pulley, to a weight. The weight employed was sufficient to produce a suction of 2 mm. pressure of mercury. The pressure was read on the manometer. The volume of the aspirator bell was calibrated with air. This was done by adding a definite quantity of water into the outer or fixed can, and then allowing the aspirator bell to come to position, and measuring the volume of air displaced by water in a gas burette. The volume of air displaced is the reciprocal of the volume of air drawn in, for the same water level in the tank. Many preliminary trials showed that four liters of water in the tank gave an air displacement of 2650 cc. on the aspirator bell. In all the experiments, therefore, this quantity of water in the fixed can was used as a standard, and the relative rate of flow of air through soils was measured by noting the time required for 2650 cc. of air to pass through the column of soil. The results obtained are shown in table 7 and on the accompanying figure 11.

TABLE 7.—EFFECT OF TEMPERATURE ON THE RATE OF FLOW OF AIR IN SOILS

| Soil. | Time required for 2650 c.c. of air to pass through soil column. | | | | | |
|---|---|---|---|---|---|---|
| | 0° C. | 10° C. | 20° C. | 30° C. | 40° C. | 50° C. |
| | Min. | Min. | Min. | Min. | Min. | Min. |
| Quartz sand | 1.45 | 1.50 | 2.00 | 2.12 | 2.28 | 2.50 |
| Sandy loam | 1.40 | 2.00 | 2.45 | 3.37 | 4.30 | 10.35 |
| Clyde silt loam | 11.00 | 15.20 | 18.30 | 21.20 | 29.30 | 41.20 |
| Clay | 11.50 | 15.00 | 18.00 | 26.00 | 31.00 | 33.00 |
| Peat | 13.30 | 16.40 | 20.15 | 20.40 | 27.30 | 38.40 |

The preceding results show that the rate of passage of air through soils decreases inversely with temperature. This is in conformity with the law of viscosity of gases as far as the order is concerned, but not in magnitude. The above velocity of transpiration is governed not only by the internal friction of the gas, but also by the swelling of the colloidal material at the higher temperatures which closes up the pores, and impedes the flow. This fact is very strikingly illustrated by the abnormal decrease in flow at the higher temperatures. The abnormal decrease at the higher temperatures, however, is also partly due to the change in structure brought about by temperature and by the transpira-

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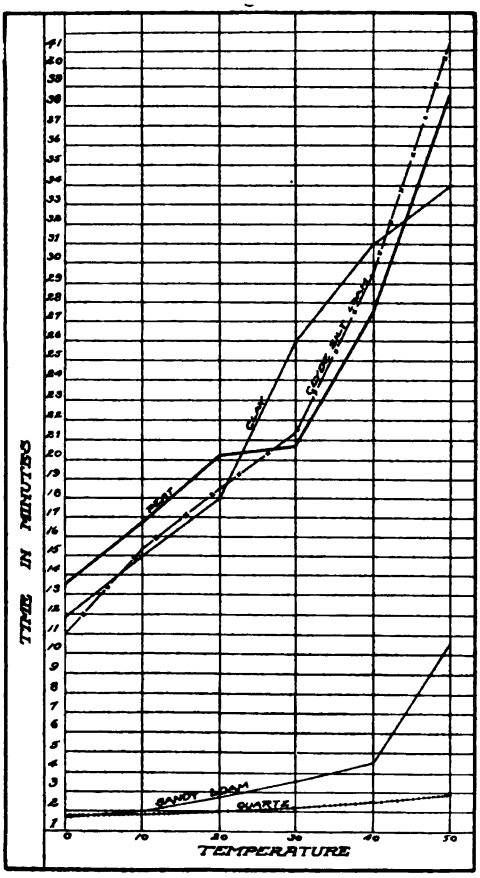


FIG. 11. CURVE SHOWING EFFECT OF TEMPERATURE ON THE RATE OF FLOW OF AIR IN SOILS.

tion of air. As the latter is sucked through the column of soil, some rearrangement of particles undoubtedly occurs. This change in structure sometimes causes either an increase or decrease in the flow of air very suddenly.

The foregoing transpiration data may be expressed also as transpiration constant for any soil and for any particular temperature. By a transpiration constant is meant the number of cubic centimeters of air which would in one second, flow through 1 cm² of cross section of a layer of soil 1 cm. thick, if the pressure were 1 mm. of mercury greater on one side of the layer than on the other. The following example will make clear how this transpiration constant can be computed. Suppose that 2650 cc. of air are drawn by the aspirator through a layer of soil 326.8 cm.² in area and 14.7 cm. thick in 105 seconds by a suction of 2 mm. of mercury. The total flow per second is 2650 ÷ 105 or 25.2 cc. per second. The flow through each square centimeter is 25.2 ÷ 326.8 or 0.077 cc. per second. The pressure gradient is 2 mm. in 14.7 cm. or 0.13 mm. per centimeter. Therefore the flow per second through each square centi-

meter for a gradient of 1 mm. per centimeter would be 0.077 ÷ 0.13 or 0.59 cc. By applying this form of computation to the foregoing experimental data the following figures are obtained.

TABLE 8.—TRANSPIRATION CONSTANT OF SOILS AT DIFFERENT TEMPERATURES.

| Soil. | 0° C. | 10° C. | 20° C. | 30° C. | 40° C. | 50° C. |
|---|---|---|---|---|---|---|
| Quartz sand | .590 | .567 | .497 | .452 | .403 | .351 |
| Sandy loam | .596 | .497 | .361 | .275 | .221 | .093 |
| Clyde silt loam | .090 | .064 | .053 | .046 | .034 | .024 |
| Clay | .084 | .066 | .055 | .038 | .032 | .030 |
| Peat | .073 | .059 | .049 | .084 | .038 | .025 |

As would be expected from the experimental results presented in table 7, the transpiration constant is greatest in soils with least colloidal matter, and decreases regularly, and in many cases very rapidly, with rise in temperature.

## EFFECT OF TEMPERATURE CHANGES ON THE AERATION OF SOILS.

Unquestionably the aeration of soils is one of the most important problems in soil physics; yet strange to say, it has never been studied experimentally from the temperature point of view. This lack of experimental study is mainly due to the prevalent notion that temperature changes occasion very little, if any, influence on the process of soil areation, because of the small cœfficient of gas expansion which amounts only to 1/273 per degree Centigrade. It is reasoned that since the average diurnal fluctuation of temperature to the depth of 12 inches is not very marked, the volume of gas diurnally exchanged in the upper one cubic foot of soil, is small. Thus King[22] has calculated that the soil ventilation due to diurnal changes in soil temperature will range from 0 up to possibly 20 cubic inches per square foot. Ramann[23], in discussing the subject, makes the following statement: "The influence of temperature fluctuations on the volume of the soil air is not appreciable, and occurs only in the upper layers of the soil. Since the coefficient of expansion of gas is only 1/273 per degree Centigrade, and inasmuch as the temperature fluctuations to the depths of from 4 to 8 inches are small, the diurnal exchange of gas is consequently small."

The problem was subjected to an experimental study and the results obtained show the remarkable fact that temperature has a tremendous influence upon the aeration of soils, and that this influence is due to two other factors besides the mere expansion of gases.

The general method of investigating the problem consisted in heating a definite volume of dry or moist soil to different temperatures and measuring (1) the volume of gas expelled, and (2) the pressure exerted. The volume of gas was measured over water in a gas burette, which is shown on figure 12, and the pressure was measured under mercury on the manometer shown also on the same figure. The soil was contained in a brass tube 8 inches long, and 1½ inches in diameter, closed at one end with a solid rubber stopper, and the other, with a single holed rubber stopper,

[22]Physics of Agriculture, p. 208 (1901).
[23]Bodenkunde, p. 386 (1911).

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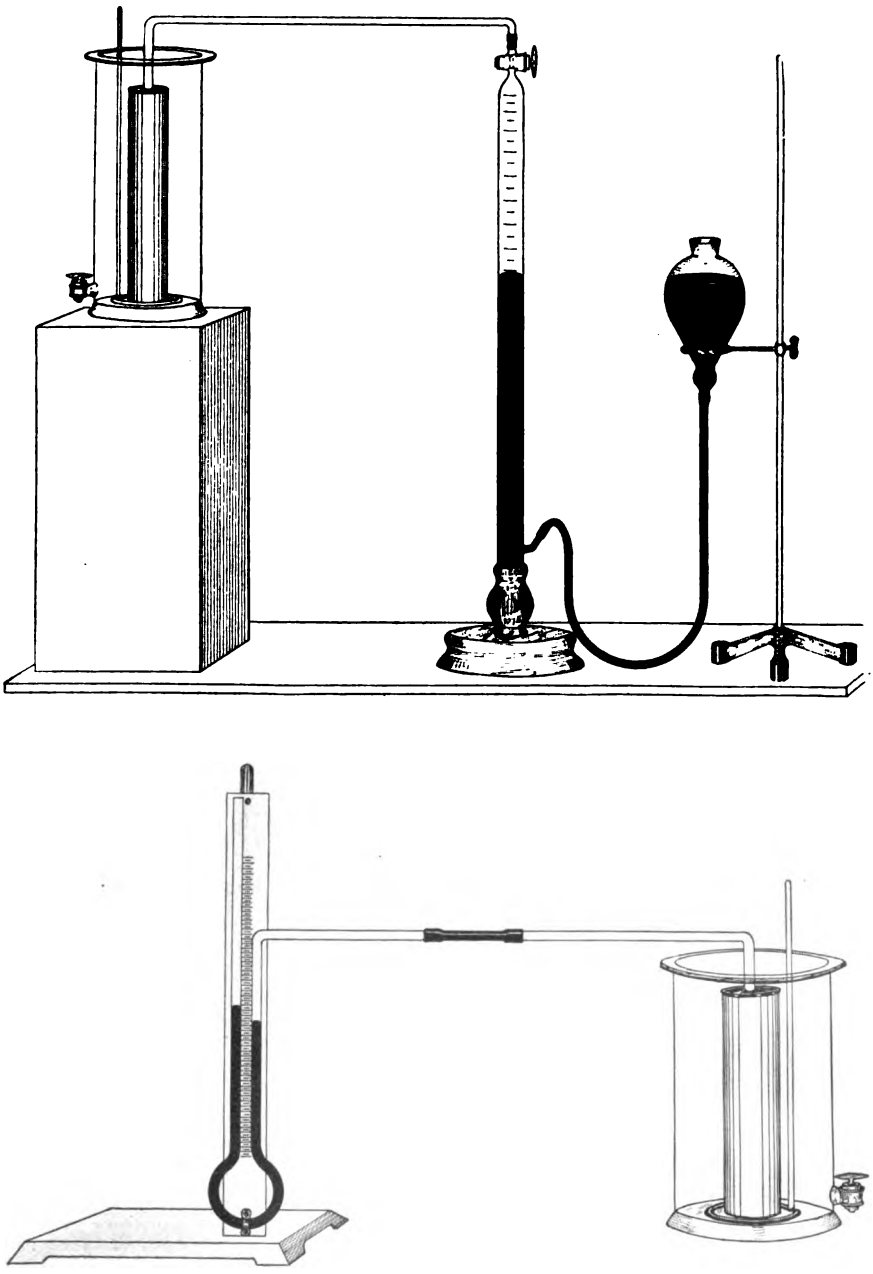

FIG. 12. APPARATUS FOR DETERMINING THE AMOUNT OF GAS EXPELLED AND ITS EXERTED PRESSURE, FROM SOILS AT DIFFERENT TEMPERATURES.

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TABLE 9.—EFFECT OF TEMPERATURE ON THE AMOUNT OF AIR EXPELLED FROM AIR DRY SOILS.

| Name of soil. | Dry wt. of soils. | Percentage porosity. | Air expelled from soil contained in tube of 152 c. c. capacity. | | | | | Total 0-50° C. | Theoretical increase for each 10°C. | Air that would be expelled from one-half cubic foot of soil. | | | | | Total 0-50° C. | Theoretical increase for each 10°C. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0-10°C. | 10-20°C. | 20-30°C. | 30-40°C. | 40-50°C. | | | 0-10°C. | 10-20°C. | 20-30°C. | 30-40°C. | 40-50°C. | | |
| | | | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. |
| Quartz sand | 212.5 | 46.6 | 3.2 | 3.5 | 3.7 | 4.0 | 4.9 | 19.30 | 2.59 | 298.2 | 326.2 | 344.8 | 372.8 | 456.7 | 1798.7 | 241.7 |
| Sandy loam | 211.9 | 45.8 | 3.1 | 3.4 | 3.6 | 4.0 | 5.0 | 19.10 | 2.55 | 288.5 | 317.4 | 335.0 | 372.2 | 465.3 | 1778.4 | 237.6 |
| Silt loam | 172.0 | 55.8 | 4.1 | 4.0 | 3.9 | 4.0 | 4.5 | 20.5 | 3.10 | 382.0 | 372.7 | 363.4 | 372.7 | 419.3 | 1910.1 | 289.5 |
| Clyde silt loam | 166.0 | 53.0 | 3.9 | 3.6 | 4.0 | 4.4 | 5.4 | 21.3 | 2.95 | 363.1 | 335.2 | 372.4 | 409.7 | 502.8 | 1983.2 | 275.0 |
| Clay | 178.4 | 51.3 | 4.0 | 3.5 | 3.6 | 3.7 | 4.5 | 19.20 | 2.85 | 372.5 | 325.9 | 335.2 | 244.5 | 419.0 | 1797.1 | 266.3 |
| Peat | 90.0 | 52.3 | 4.5 | 4.3 | 4.4 | 4.7 | 5.4 | 23.3 | 2.91 | 419.1 | 400.5 | 409.8 | 437.8 | 503.0 | 2167.5 | 271.4 |
| Empty tube | 00.00 | 100.0 | 6.4 | 6.5 | 6.3 | 6.2 | 6.1 | 31.0 | 5.57 | 596.2 | 605.5 | 586.9 | 577.6 | 568.2 | 2934.4 | 518.7 |

TABLE 10.—EFFECT OF TEMPERATURE ON THE AMOUNT OF AIR EXPELLED FROM MOIST SOILS.

| Name of soil. | Dry wt. of soil, grams. | Per cent. moisture. | Per cent porosity. | Air expelled from soil contained in tube of 152 c. c. capacity. | | | | | Total. | Theoretical increase for each 10° C. | Air that would be expelled from one-half cubic foot of soil. | | | | | Total 0-50° C. | Theoretical increase for each 10° C. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0-10°C. | 10-20°C. | 20-30°C. | 30-40°C. | 40-50°C. | | | 0-10°C. | 10-20°C. | 20-30°C. | 30-40°C. | 40-50°C. | | |
| | | | | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c. | c. c |
| Quarts sand | 187.0 | 7.02 | 45.40 | 3.5 | 3.6 | 3.9 | 4.7 | 5.9 | 21.60 | 2.52 | 326.1 | 335.4 | 363.3 | 437.9 | 549.6 | 2012.3 | 235.5 |
| Sandy loam | 162.2 | 11.00 | 48.18 | 3.1 | 3.8 | 4.1 | 4.5 | 6.0 | 21.50 | 2.68 | 288.8 | 354.0 | 382.0 | 419.3 | 559.0 | 2003.1 | 250.0 |
| Silt loam | 144.2 | 18.6 | 46.98 | 3.5 | 3.6 | 4.6 | 5.0 | 6.1 | 22.80 | 2.62 | 325.7 | 335.0 | 428.1 | 465.3 | 567.6 | 2121.7 | 243.7 |
| Clyde silt loam | 106.5 | 27.09 | 53.23 | 3.8 | 3.9 | 4.3 | 5.0 | 6.4 | 23.40 | 2.96 | 354.0 | 363.4 | 400.6 | 465.9 | 596.3 | 2180.2 | 276.0 |
| Clay | 111.6 | 25.28 | 50.32 | 3.9 | 4.1 | 4.6 | 5.4 | 6.5 | 24.50 | 2.80 | 363.2 | 381.8 | 428.3 | 502.8 | 605.3 | 2281.4 | 261.0 |
| Peat | 4.9 | 91.97 | 38.63 | 5.0 | 5.5 | 6.0 | 7.0 | 8.5 | 32.00 | 2.15 | 465.9 | 512.5 | 559.0 | 657.2 | 792.0 | 2981.6 | 200.4 |
| Empty tube | ..... | ..... | 100.00 | 5.8 | 5.9 | 5.8 | 6.0 | 5.7 | 29.2 | 5.57 | 596.2 | 605.5 | 586.9 | 577.6 | 568.2 | 2720.2 | 518.7 |

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TABLE 11.—EFFECT OF TEMPERATURE ON THE AMOUNT OF PRESSURE EXERTED BY MOIST SOILS.

| Name of soil. | Dry wt. of soil. grams. | Percentage of moisture. | Percentage of porosity | Pressure exerted by soils contained in tube of 152 c. c. capacity. | | | | | Total. | Pressure that would be exerted by one-half cubic foot of soil. | | | | | Total. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0-10°C. Atms. | 10-20°C. Atms. | 20-30°C. Atms. | 30-40°C. Atms. | 40-50°C. Atms. | Atms. | 0-10°C. Atms. | 10-20°C. Atms. | 20-30°C. Atms. | 30-40°C. Atms. | 40-50°C. Atms. | Atms. |
| Quarts sand | 187.0 | 7.02 | 45.40 | 0.0342 | 0.0414 | 0.0454 | 0.0579 | 0.6908 | 0.2480 | 3.187 | 2.859 | 4.229 | 5.394 | 6.436 | 23.105 |
| Sandy loam | 162.2 | 11.00 | 48.18 | 0.0342 | 0.0408 | 0.0460 | 0.579 | 0.0723 | 0.2626 | 3.187 | 3.800 | 4.291 | 5.395 | 6.498 | 23.171 |
| Silt loam | 144.2 | 18.16 | 46.98 | 0.0342 | 0.0421 | 0.0460 | 0.0605 | 0.0710 | 0.2592 | 3.187 | 3.924 | 4.291 | 5.517 | 6.498 | 23.418 |
| Clyde silt loam | 106.5 | 27.09 | 53.23 | 0.0363 | 0.0447 | 0.0487 | 0.0605 | 0.0723 | 0.2626 | 3.379 | 4.163 | 4.530 | 5.633 | 6.734 | 24.439 |
| Clay | 111 6 | 25.28 | 50.32 | 0.0355 | 0.0441 | 0.0480 | 0.0605 | 0.0710 | 0.2592 | 3.308 | 4.105 | 4.472 | 5.635 | 6.616 | 24.136 |
| Peat | 4.9 | 91.97 | 38.63 | 0.0460 | 0.0552 | 0.0671 | 0.0776 | 0.0894 | 0.3355 | 4.291 | 5.150 | 6.253 | 7.234 | 8.337 | 31.265 |
| Empty tube | ..... | ..... | 100.00 | 0.0342 | 0.0368 | 0.0355 | 0.0368 | 0.0368 | 0.1802 | 3.1877 | 3.432 | 3.309 | 3.432 | 3.432 | 16.79 |

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which contained a bent glass tube to be connected to the gas burette. The soil column in the tube occupied a space of 152 cubic centimeters, and was about 6.5 inches in length. The length was calculated to represent the depth that the upper surface of soil is tilled, and in which the amplitude of temperature is most marked. There were six different classes of soil used, namely: quartz sand, and sandy loam, silt loam, and clay of the Miami series, and Clyde silt loam and peat. All these soils, both in the dry and moist condition, were passed through a sieve, mixed well, and compacted in the tube as uniformly as possible. The packing was done by allowing the tube to fall in a vertical position a certain number of times from a definite height. The soil was heated to any desired temperature by varying the temperature of the water contained in the vessel in which the soil tube was placed. There were six different temperatures employed, 0°, 10°, 20°, 30°, 40°, and 50° C. These temperatures are within the limits of the temperature changes that occur in the bare soil between winter and summer, and between day and night in succession, or at intervals of a few days. The soil was kept at the same temperature until no more gas was expelled or pressure exerted. In the case of the moist soil the equilibrium was attained in about 30 minutes, but in the case of the dry soils, a somewhat longer time was required. It is doubtful, however, whether all the air was expelled, even when equilibrium was established, because there are films or small bubbles of air which adhere with great tenacity to particles, and especially to those coated with oily substances. Moreover, some air is imprisoned and cannot escape. Some very slight irregularities which will be noticed in some of the results, may be attributed to these factors. But the error resulting from the difficulty of expelling all the gas must relatively be very small on account of the large volumes of gas expelled. The following tables and diagrams represent the results obtained. Table 9 contains the ob-

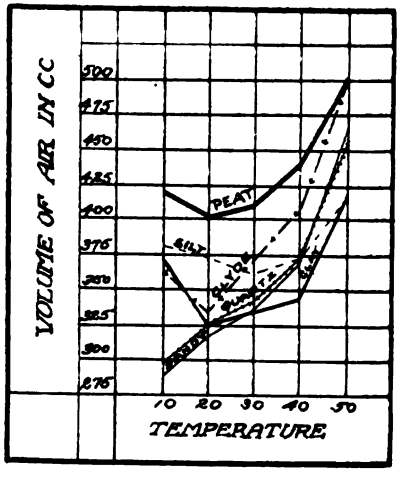


FIG. 13. CURVE SHOWING THE EXPULSION OF AIR FROM ONE HALF CUBIC FOOT OF AIR DRY SOIL AT DIFFERENT TEMPERATURES.

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tained and calculated data for the volume of gas expelled from the dry soils. Table 10 contains the identical data for the moist soils. These tables are accompanied by figures 13 and 14 respectively. Table 11 represents the amount of pressure exerted by the moist soils only. The data of this table is shown on figure 15.

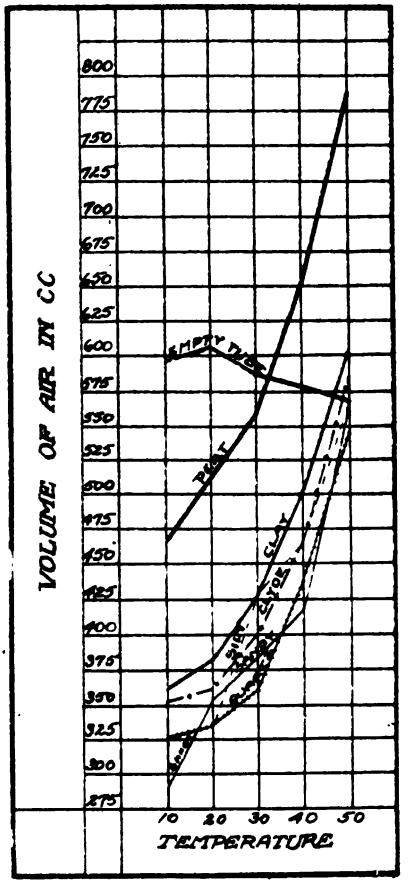


FIG. 14. CURVE SHOWING THE EXPULSION OF AIR FROM ONE HALF CUBIC FOOT OF MOIST SOIL AT DIFFERENT TEMPERATURES.

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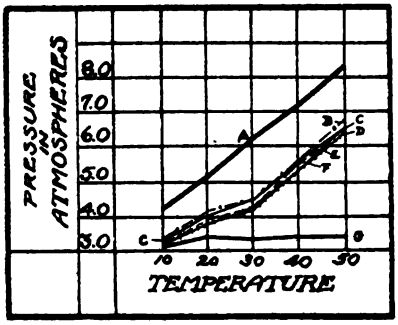


A—Peat.
B—Clyde Silt Loam.
C—Clay.
D—Quartz.
E—Sandy Loam.
F—Silt Loam.
G—Empty Tube.

FIG. 15. CURVE SHOWING THE PRESSURE EXERTED BY AIR IN ONE HALF CUBIC FOOT OF MOIST SOIL AT DIFFERENT TEMPERATURES.

Before entering into the discussion of the data presented in the preceding tables and charts, an explanation of their form of presentation is necessary. The first eleven columns of tables 9 and 10 show the weight of the soils contained in the tube, the percentage of pore space, etc., and the actual number of cubic centimeters of air obtained at the various temperatures. The last seven columns to the right show the same experimental results reduced to the volume of air that one-half cubic foot of soil would give, provided it had the same percentage of pore space as the soil in the tube. This basis makes the figure more practicable and more comprehensible. As will be seen, the volumes are not reduced to the standard condition of temperature and pressure, which can be done by the use of the formula of $V_0 = V \frac{P}{760\ (1 + 0.00367t)}$ or $V_0 = V \frac{P - M}{760\ (1 + 0.00367t)}$ where $V_0$ is the volume under standard conditions, V the observed volume, P the pressure expressed in millimeters of mercury, t the observed temperature, and M the vapor pressure of the liquid, because the data as given above represent more closely the true state of affairs. As will be shown later, the amount of gas expelled or pressure produced, are very greatly influenced by the aqueous vapor present, and if the results were reduced to the standard conditions, this factor would have to be eliminated. The principal object of the research is to ascertain to what extent temperature affects the ventilation of soils in *toto*, and not necessarily the increase of volume of the pure gases in the soil. Nor are the data reduced to any common pressure. The atmospheric pressure varied about .20 inches on the barometer for different experiments. Repeated tests showed, however, that the error resulting from the difficulty of expelling all the gas from the soils, exceeds that due to the small variations in the atmospheric pressure. Hence, the changes in atmospheric pressure have been disregarded in

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the calculation of the preceding results. The first ten columns of table 11 show the actual pressure in atmospheres of mercury that the experimental soils produced, and the last seven columns represent the same data reduced to the basis of one-half cubic foot of soil, the percentage of pore space in the experimental soil being taken as a basis.

With these explanatory remarks in mind, the discussion of the data may now be undertaken. Disregarding for the present table 9 with the dry soils, and considering only table 10 with the moist soils, *it will be found that temperature exerts a great influence on the aeration of soils.* The quantity of gas that would actually be exhaled or inhaled by raising the temperature of the upper half cubic foot of soil from 0° to 10° C., amounts to 326.2 cc. in the quartz sand, 288.8 in sandy loam, 325.7 in silt loam, 354.0 in Clyde silt loam, 363.2 in clay, and 465.9 in peat. These volumes increase very regularly and markedly with rise in temperature so that at the temperature elevation of from 40° to 50° C. they amount to 549.5 cc. in quartz sand, 559.0 in sandy loam, 567.6 in silt loam, 596.3 in Clyde silt loam, 605.3 in clay and 792.0 in peat. It must be noted that this increase in volume with a rise in temperature is contrary to the law of Charles which states that "providing the pressure remains constant the volume of a gas will change 1/273 for each degree of change of temperature." In the present case the pressure, which is the atmospheric, remained constant throughout the duration of the experiment. According to this law the results should follow the formula $V = V_0 (1 + at)$ in which $V_0$ represents the volume of the gas at 0° and V the volume at a temperature of t and $a = 1/273$, so that the increase in volume for every rise of 10° C. should be the same for all equal temperature increments. The last column to the right shows the theoretical increase in volume of air contained in the total pore space of the upper half cubic foot of soil, for every raise of 10° C. up to 50° C. By comparing this theoretical increase in volume with the actual increase obtained at the different temperature elevations, the remarkable fact becomes at once evident that the latter not only rises with every increment of temperature, while the former remains the same, but also the difference between the two is very marked even at the temperature elevation of from 0° to 10° C., and that it is gradually accentuated with further rise in temperature so that at the temperature elevation of from 40°-50° C. it is, in most cases about 4 times greater than that at 0°-10° C. For example, at the temperature elevation of from 0° to 10° C, the difference in volume increase between the actual and theoretical is 90.6 cc. for quartz sand, 38.8 for sandy loam, 82.0 for silt loam, 78.0 for Clyde silt loam, 102.2 for clay, and 265.5 for peat. While at the temperature elevation of from 40° to 50° C. the difference is 314.1 cc. for quartz sand, 309.0 for sandy loam, 323.9 for silt loam, 320.3 for Clyde silt loam, 344.3 for clay and 592.6 for peat. It will also be seen that the increase in volume of the actual results is 50 per cent greater from the rise of temperature of from 40° to 50° C. than that from 0° to 10° C., while the increase in volume of the theoretical results is the same at both increments of temperature.

The horizontal line to the left headed "empty tube" contains some very important information in connection with what has been said above. This column contains the increase in volume of the air enclosed in an empty tube of exactly the same capacity as that contained the soils. The air in this tube was dried by heating the tube to 100° C. and then cooling it gradually to 0° C. and allowing air to pass either through

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$CaCL_2$ or $H_2SO_4$ before it entered the tube. This procedure had an object in view which will be revealed subsequently. Since the tube was empty its "porosity" was 100 per cent. Reducing, for sake of comparison, its volume to that of an empty half-cubic foot, the increase in volume of the air by increments of 10° C. will be found at the bottom of the right hand half of the table. An examination of these results show that they follow the law of Charles in that the increase in volume is the same for equal raise in temperature. The total increase in volume from 0° to 50° C. is greater than that of quartz sand, sandy loam, silt loam, Clyde silt loam, and clay but is 261.4 cc. less than that of peat. *This is indeed very interesting, the half cubic foot tube filled with moist peat and having a pore space of 5470 cc. should give a greater increase in volume of air from a temperature rise of from 0° to 50° C. than the same half cubic foot tube containing nothing but dry air, and having a pore space of 14,160 cc.* On the other hand, when the air of this empty tube is not previously dried, the increase in volume for every 10° C. raise of temperature ascends exactly as that of the moist soils, and that the total volume increase is far greater than that of all the soils, including peat. This difference in the results between the dry and moist air in the tube suggested the explanation as to the cause of the difference between the actual and calculated results already considered.

Taking up now table 10 with the air dry soils, it will be seen that the results follow in order those of the moist soils. The only difference is that in the former the actual increase in volume with the various increments of temperature is not so marked and so regular, and that the total volume increase is not so great, as in the latter. An explanation for these apparent variations will be offered subsequently.

Table 11 and the accompanying figure 14 show, as already stated, the pressure exerted in atmospheres of mercury by the moist soils contained in the tube of 152 cc. capacity, or in half cubic foot (14,160 cc.) tube. *An examination of these data will at once reveal the fact that the pressure produced by the increase in volume with rise in temperature is tremendous.* The amount of pressure that would actually be produced by raising the temperature of the upper half cubic foot of soil from 0° to 10° C. amounts 3.187 atmospheres in quartz sand, 3.187 in sandy loam, 3.187 in silt loam, 3.379 in Clyde silt loam, 3.308 in clay, and 4.291 in peat. This pressure increases in all the soils regularly and rapidly with a rise in temperature so that the temperature elevation of from 40° to 50° C. the pressure exerted by the quartz sand is 6. 436 atmospheres, by the sandy loam 6.498, by the silt loam 6.498, by the Clyde silt loam 6.734, by the clay 6.616 and by the peat 8.337. Evidently the pressure increases as abnormally as the volume, and consequently both must possess a common cause. Theoretically, the amount of pressure produced by the various 10° C. increments must be the same as the results of the empty tube show, which were obtained from dried air.

The foregoing abnormalities, both in the volume and pressure increase with a continued rise in temperature, and the great deviation from the theoretical volumes as calculated from the porosity of the soil, are due (1) to the pressure or expansion of the water vapor, and (2) to the gases absorbed by the soils and given off at the various temperatures.

As already mentioned, water is transformed into vapor by the application of heat and the quantity vaporized increases with rise of temperature, and is usually deduced from the pressure exerted. The

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following table shows the great influence that temperature has upon the vapor pressure.

TABLE 12.—TENSION OF AQUEOUS VAPOR.

| Temperature. | Pressure in millimeters. | Temperature. | Pressure in millimeters. |
|---|---|---|---|
| 0°.0 | 4.5687 | 30°.0 | 31.5096 |
| 5°.0 | 6.5067 | 35°.0 | 41.827 |
| 10°.0 | 9.1398 | 40°.0 | 54.906 |
| 15°.0 | 12.6739 | 45°.0 | 71.391 |
| 20°.0 | 17.3632 | 50°.0 | 91.982 |
| 25°.0 | 23.5174 | | |

It will be seen that the vapor pressure increases very regularly and rather markedly with rise in temperature. At the temperature of 0° C. the pressure is 4.5687 millimeters, while at 50° C. it is 91.982 millimeters. From these figures it can be easily conceived why the volume of air expelled from the moist soils, and the pressure exerted by the air of the same soils, do not follow the laws of Charles, but instead, they increase differently at the various temperatures, and that the actual values are far greater than the theoretical. To obtain, therefore, the real increase in volume and pressure of the air alone, containing no moisture, the increase in volume and pressure due to the aqueous vapor must be deducted from the foregoing experimental data. This can be done by the use of suitable formulae but it would be of no practical value because the data then would not show the complete influence of temperature upon soil ventilation. The expansion or pressure of this aqueous vapor is dependent upon the temperature and upon the nature of the liquid, but it is not affected by the pressure of other gases nor by the amount of the liquid present. If a closed space, such as the tube here used is filled with a mixture of gases, each gas will exert a definite pressure which is the same whether it exists alone in the space or whether other gases are present. The total pressure of the gas mixture is the sum of the partial pressure of the various gases. The partial pressure of the aqueous vapor can be determined by the formula already given, provided the gas is saturated. In the moist soil the air was saturated, but in the dry soils it was not, and some irregularities observed in the latter soils, are attributed to this fact.

As already stated it has long been known that absoption of gases by solids decreases with temperature. This fact was verified in the present investigation. In order to ascertain to what extent absorption influenced the foregoing abnormal results, on soil aeration, a series of experiments was conducted upon the subject. The problem was investigated by filling the usual tube with air dry soil and drying the latter in an oven for several hours at a temperature of 105° C. By holding the tube horizontally the solid rubber stopper and the rubber stopper which contained the bent tube, were inserted at the opposite ends. To the bent tube was attached also a tube containing $CaCl_2$. As the soil cooled it drew air through the $CaCl_2$, the latter absorbed the water vapor and thus dried the air as it entered the soil tube. The soil was cooled to 0° C. and allowed to remain at that temperature for a few hours to absorb gas and come to an equilibrium. The temperature was then raised to different degrees and the gas expelled measured in

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the usual manner. The quantity of gas given off was taken as a measure of the amount that would be absorbed at the same temperature since expulsion is the reciprocal of absorption. Attention must be called here, however, to the fact that the porosity of the material comes into play and consequently not all of the gas given off or taken up at the various temperatures, is due to absorption. The soils employed were the same as those in the preceding series of experiments. The results obtained are detailed herewith.

TABLE 13.—EFFECT OF TEMPERATURE ON ABSORPTION OF GASES.

| Soil. | Dry wt. of soils. | Capacity of tube. | 0-10°C. c. c. | 10-20°C. c. c. | 20-30°C. c. c. | 30-40°C. c. c. | 40-50°C. c. c. | Total c. c. |
|---|---|---|---|---|---|---|---|---|
| Quartz sand..... | 202.5 | 152 | 3.3 | 2.8 | 2.8 | 2.8 | 2.5 | 14.2 |
| Sandy loam..... | 221.6 | 152 | 3.9 | 3.6 | 3.0 | 3.0 | 2.6 | 16.1 |
| Clyde silt loam..... | 164.5 | 152 | 5.0 | 4.3 | 4.2 | 4.0 | 3.6 | 21.1 |
| Clay..... | 182.5 | 152 | 4.8 | 4.4 | 4.2 | 4.1 | 3.8 | 20.30 |
| Peat..... | 92.0 | 152 | 6.1 | 5.4 | 5.0 | 4.9 | 4.5 | 25.9 |

It will be seen from the above table that the amount of air given off (or absorbed), decreases regularly and gradually with temperature. It will also be observed that the total quantity is greatest in peat and decreases with Clyde silt loam, clay, sandy loam and quartz in order respectively.

From these results it is evident that absorption of gases by dry soils influences the æration of soils principally at the lower temperatures and that at the higher temperature it is the aqueous vapor which plays the most important and greatest role.

It should be mentioned, however, in passing that a certain amount of the gases expelled from moist soil with the elevation of temperature is due also to that absorbed by the soil water. How much of the total volume owes its origin to this source it cannot be stated definitely as no experimental work was performed on the subject, but probably it is comparatively very small.

*Thus we see that temperature has a tremendous influence upon soil aeration and in a manner not heretofore altogether realized.* It is true that the diurnal temperature amplitudes are not very appreciable below six inches, but above this depth, which constitutes that layer of soil most tilled, they are very large, and especially in certain regions of the world. Field experiments on soil temperature at this Station, which have been running for four years, show that the diurnal fluctuation in temperature in the different types of bare soil, is sometimes as high as 25° C. for the first inch depth, 15° for the second, 13° for the third, 10° for the fourth, 8° for the fifth, and 6° for the sixth, making an average of about 13° C. for the upper six inches. As a rule these fluctuations are larger for the sandy soils and smaller for the muck and peat and still smaller in cropped soils. During the warm part of the year there occurs very often excessive hot and cold days only a short distance apart. The difference between the maximum soil temperature of the excessively hot day and the minimum soil temperature of the excessively cold day sometimes amounts to 40° C. at the upper first inch of soil. On the other hand, it must also be remembered that the soil temperature undergoes great changes between summer and winter and the influence of temperature on

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soil aeration must be considered from this standpoint also. Hence, the temperature ranges employed in this investigation are within the limits of the diurnal and seasonal changes that actually occur in the soil.

At this point the reader may appear to be noticing certain discrepancies in the conclusions of the present research in comparison with those on the "Movement of Moisture from Moist and Warm Column of Soil to Dry and Cold Column of Soil with an Air Space between the two Columns." In this latter research it was concluded that the amount of water moved through vapor, from a point of high to a point of low temperature, and the amount of water lost from the soil through diffusion of water vapor, are practically negligible. In the present research, it has been seen that temperature causes the expulsion of enormous amounts of gas from the soil, and that this abnormal increase in volume of gas expelled is due to aqueous vapor. The reader may now ask, How are these facts reconciled, If rise of temperature causes the expulsion of air from the soil which contains moisture, then the amount of water lost from the soil through vapor alone must be very large. The answer to these questions will be found in the following table which contains the amount of water vapor required to saturate a given quantity of air at different temperatures. The amount of water vapor which saturates a given quantity of air is usually expressed in grains per cubic foot or grams per cubic meter, or it may be expressed in terms of the pressure which it exerts in millimeters or inches.

TABLE 14.—AMOUNT OF WATER VAPOR REQUIRED TO SATURATE A GIVEN QUANTITY OF AIR AT DIFFERENT TEMPERATURES.

| Temperature degrees F. | Vapor pressure, inches. | Amount of water vapor in grains per cu. ft. | Temperature degrees C. | Vapor pressure, m. m. | Amount of water vapor in grains per cu. m. |
|---|---|---|---|---|---|
| ..... | ..... | ..... | 0 | 4.57 | 4.87 |
| ..... | ..... | ..... | 10 | 9.14 | 9.36 |
| ..... | ..... | ..... | 20 | 17.36 | 17.15 |
| 30..... | 0.166 | 1.97 | 30 | 31.51 | 30.08 |
| 40..... | 0.246 | 2.86 | 40 | 54.87 | 50.67 |
| 50..... | 0.360 | 4.09 | ..... | ..... | ..... |
| 60..... | 0.517 | 5.76 | ..... | ..... | ..... |
| 70..... | 0.732 | 7.99 | ..... | ..... | ..... |
| 80..... | 1.022 | 10.95 | ..... | ..... | ..... |
| 90..... | 1.408 | 14.81 | ..... | ..... | ..... |
| 100..... | 1.916 | 19.79 | ..... | ..... | ..... |

Considering the figures of the Centigrade scale it will be seen that the amount of water contained in a cubic meter (1000 liters) of saturated air at 20° C. is only 17.15 grams. That means that if 1000 liters of saturated air are expelled from the soil at the temperature of 20° C. only 17.15 grams of water will be lost from the soil. In table 10, it is shown that by raising the temperature of one-half cubic foot of soil from 0° to 50° C. only about two liters of air will be expelled from the mineral soils and about three liters from the peat. On the other hand, the air expelled from the soil as the temperature rises, cannot be said that it is always saturated. Hence, the amount of water that may be lost from the soil through expulsion of soil air incident to soil ventilation, is insignificant.

Before closing this section, one more point should be considered;

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namely, the effect of temperature upon the atmospheric pressure, and its influence in turn upon the aeration of soils.

The diurnal variation of the atmospheric pressure may be classified thus: the chief maximum usually occurs at about 10 in the morning, the chief minimum at 4 in the afternoon, a secondary maximum at 10 in the evening, and a secondary minimum at 4 in the moruing. The pressure is thus subject to double oscillation in the course of a day. The amplitude or amount of daily variation is always small, never amounting to more than 0.2 of an inch, and in many places being often less than a tenth of this.

Now, temperature undoubtedly plays a large part in causing this diurnal variation but the exact way in which it operates to produce the result cannot be satisfactorily stated. Theoretically, however, the maximum would be expected at the time of least temperature, that is, at about sunrise, and the minimum at the highest temperature, that is, from 1 to about 3 o'clock in the afternoon. At these respective periods the surface soil also attains its maximum and minimum temperature. At these maximum and minimum temperatures there occurs the greatest amount of gas exhaled or inhaled. Hence, atmospheric pressure, as influenced by temperature, tends to aid in the ventilation of soil, but in a very small degree, if any, since its diurnal variation is so insignificant.

## SUMMARY.

In this bulletin there are presented the results of an investigation upon the influence of temperature on certain physical processes in the soil, such as the capillary movement and retention of moisture, gravitational flow of water, thermo-osmose, gas flow, aeration of soils, etc. It was pointed out at the outset that the influence of temperature upon these physical processes in the soil lacked experimental study and consequently our knowledge consisted almost entirely from *a priori* deductions from the physical laws of surface tension of liquids, viscosity of liquids and gases, and expansion of gases, as affected by temperature. The general problem was subjected to an experimental study and the results obtained may be summarized as follows:

The investigation upon the effect of temperature on the movement of water vapor and capillary moisture in soils shows that:

(1) When one-half of a column of soil of uniform moisture content is maintained at 20° and 40° C. and the other half at 0° C. for eight hours, the percentage of water moved from the warm to the cold soil increases in all the different types of soil with rise in moisture content until a certain water content is reached and then it decreases with further increase in moisture content. The results then plot into a parabola. The percent of moisture at which the maximum thermal translocation of water occurs is different for the various classes of soil, but the percentage of the maximum thermal translocation of water is about the same for all classes of soil for any one of the temperature amplitudes. The percentage of moisture at which this maximum thermal translocation occurs is designated as *thermal critical moisture content.*

These results are contrary to what might be expected from the laws

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of surface tension and viscosity. They have led to the conclusion that the capillary movement of water in moist soils is not controlled entirely by the curvature of the capillary films, as is generally believed, but also by the unsatisfied attractive forces of the soil for water.

(2) When a moist column of soil is kept at 20° and 40° C. and a dry column of soil at 0° C. for eight hours, and the two columns are separated by an air space, the percentage of moisture distilled over from the moist and warm column to the dry and cold column of soil is very insignificant for both amplitudes of temperature, and about the same for all moisture contents.

These results lead to the conclusion (a) that the amount of water lost from the soil by water vapor is very small, (b) that there is no rising of vapor during the night from the warmer soil below to the cold soil above, and (c) that the source of water of the dew is not derived from the soil vapor, as is commonly believed.

(3) When a moist column of soil is in contact with a dry column of soil and the former is kept at 20° and 40° C. and the latter at 0° C. for eight hours, the amount of moisture moved from the moist and warm soil to the dry and cold soil increases with temperature and with moisture content. But when the moist column of soil is maintained at 0° C. and the dry column of soil at 20° and 40° C. for the same number of hours, there is very little, if any, movement of water from the former to the latter.

These results have led to the conclusion that temperature has a very marked influence on the conservation of moisture by mulches.

(4) No thermo-osmotic phenomena were observed in soils.

(5) The research on the effect of temperature on the rate of percolation of water in soils shows that in the case of sandy loam, silt loam, clay loam, clay and muck the rate of flow increases with rise in temperature up to about 30° C. and then decreases with further rise in temperature. In the case of sand, however, the rate of flow increases with a constantly rising of temperature. In the former soils the results are explained under the hypothesis that the colloidal material present swells with increase in temperature and tends to close the channels through which the water flowed.

(6) The water holding capacity of soils decreased with rise in temperature, but this decrease is not due entirely to the diminished surface tension of the soil water but also to other factors.

(7) The rate of flow of air through soils decreases with rise in temperature. This dimunition is not entirely due to the increased viscosity of the gases, but in addition to some changes which the temperature produces in the soil.

(8) Temperature has a tremendous influence upon the aeration of soils. This influence is not due merely to the expansion of gases of the soil, as is commonly believed, but also to the absorption of gases by the soil at different temperatures, and to the aqueous vapor.

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TECHNICAL BULLETIN NO. 23 NOVEMBER, 1915

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# A SIMPLIFIED APPARATUS FOR MEASURING THE CONDUCTIVITY OF ELECTROLYTES.

BY
R. P. HIBBARD
C. W. CHAPMAN

EAST LANSING, MICHIGAN
1915

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## FOREWORD.

This bulletin entitled "A Simplified Apparatus for Measuring the Conductivity of Electrolytes" is mainly technical physics and discusses the means of improving and making more accurate the methods of determining the conductivity of solutions. The bearing that this has on certain plant physiological investigations comes from the fact that in studying the question of nutrition, in particular, of the absorption of water and mineral nutrients, it is essential to have very accurate means of determining the salt content of the solutions used before, during, and at the close of experiments.

When Dr. Hibbard began experiments, the known methods were found to be either comparatively crude, or exceedingly complicated, but with the help of Professor Chapman he has simplified the apparatus very greatly while at the same time he has improved its accuracy to an equal degree.

I feel that this bulletin will be of value to workers in similar lines elsewhere as well as to physicists and chemists in general who demand very accurate means of determining in the electrical way the salt content of solutions.

ERNST A. BESSEY.



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# A SIMPLIFIED APPARATUS FOR MEASURING THE CONDUCTIVITY OF ELECTROLYTES.

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C. W. CHAPMAN, ASSISTANT PROFESSOR OF PHYSICS.

## 1. INTRODUCTION.

The most important problem in plant physiology is doubtless the general one of nutrition. Under this heading there are numerous subsidiary problems which have partially or entirely evaded explanation. Until recent years physiologists have had to depend upon the known facts of physics and chemistry, but now the closely allied subject of physical chemistry, which has been making rapid strides in the past ten or fifteen years, reveals many principles which offer invaluable aid. It is true that many subjects in this comparatively new science do not touch directly the activities of plants, but there are others which concern the student of plant physiology very closely. The newer knowledge of *solutions* is of fundamental importance. In no condition outside and inside the plant does matter play a more important physiological role than in a state of solution in water. Some soil solutions are dilute in respect to the minerals present in them and no doubt the solutes undergo a more or less complete dissociation, the former being true at infinite dilution. These solutes no longer exist as definite chemical compounds but are split up into part-molecules or ions each of which carries a charge of electricity and thereafter whatever properties the solutions may possess are due to the properties of these ions and the undissociated molecules when present.

The plasma membrane surrounding the living portion of each cell prevents the entrance of any substance not in solution. Thus the knowledge of the behavior of solutions is of greatest value for a proper interpretation of the absorption of electrolytes from the soil. Recent data obtained from conductivity measurements lend support to the theory that the solutes in the soil solution enter the plant in ionic form. The general problem of permeability has received added impetus through the application of certain principles of physical chemistry. To the plasma membrane has been assigned the property of selective permeability and it is here also probable that we are concerned with ion permeability. Perhaps the most accurate and at any rate the simplest method for determining the changes in permeability, since doubt has been cast on the plasmolytic method, is the one of electrical conductivity. In the hands of Prof. W. J. V. Osterhout (19-31) the method has brought out many interesting facts. Permeability is altered by a variety of substances and conditions, and the plasma membrane is proteid rather than lipoidal in nature. The cell must be considered as a dynamic entity passing through various transformations and existing in a medium that is continually changing in a chemical and in a physical way. These complex conditions must give rise to new relations between the membrane, the various parts of the



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cell, and its environment. Consequently the permeability of the membrane will be constantly changing. It is better to accept the view of selective permeability, though we cannot explain it in its intricate phases, than to assume that the membrane is quite impermeable to many of the solutes and that when these do penetrate, the membrane must "leak."

The concentration of the cell sap is rarely or never the same as that of the solution outside the plant, or in the conducting tissues of the plant. There is therefore established a movement of water into the cell, and a production of a hydrostatic pressure equivalent to the osmotic pressure of the dissolved substances. This pressure pushes the protoplasm outward and keeps the membrane tense and rigid. Osmotic pressure therefore has a definite function. It maintains and regulates turgor. A knowledge of solutions is necessary to a proper understanding of this phenomenon.

Much information has been collected to show that the molecules of solutes obey the well known laws of gases. A substance in solution in water acts essentially as a gas. These particles are not so free to move as in the gaseous state because of the friction between them and the molecules of water and thus great pressures are necessary to move them through the water or to separate them. This applicability of the laws of gases to solutes has made evident the proper basis of comparison between solutions of different compounds. So, now, solutions for comparison are equimolecular ones, and are not made on the percentage basis. We must take this fact into consideration in studying the influence of different salt solutions or nutrient solutions on the physiology of plants. The problems of balanced solution and antagonistic action have depended almost entirely for their explanation on a knowledge of physical chemistry.

Conductivity measurements have helped immensely in the study of the influence of concentration on the absorption and excretion of solutes by the roots of plants while growing in dilute culture solutions. There is a certain concentration for each salt or mixture of salts at which the roots excrete and absorb electrolytes at the same rate. At certain concentrations on either side, one function overbalances the other. Thus a knowledge of the culture concentration which is best fitted for the development of the plant can be obtained through conductivity studies. The conductivity method is the easiest and most accurate, since the resistance to the passage of an electric current is a function of the number of ions present in the solution, and the number of ions is in turn the index of the concentration. This is true only in dilute solutions where complete dissociation has taken place.

The presence of colloids, that are of constant occurrence in the soil, gives rise, in the soil solution, to a phenomenon called adsorption. Altho a subject containing little that is definitely known, it is nevertheless of much importance. A more thorough study from the vantage point of our present knowledge of physical chemistry should clear up much of the haze that envelops this subject. Physical adsorption as it is often called to distinguish it from absorption and chemical combination is defined as a concentration of one component on the interface between two phases. In dilute solution the solute is very likely adsorbed in ionic condition and if the assumption is true, that the adsorbed ions are then inoperative, the conductivity of the solution would be a measure of the amount of

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adsorption. In complex systems special conditions would arise and introduce errors which would have to be rectified in some way, in order to make this method applicable.

Certain physiologists, pathologists, biochemists, and others have made use of conductivity methods, but, because of inaccuracies and difficulties attendant upon a measurement, comparatively little work except of a general nature has been done. The names of Roth (33), Bugarzky and Tangle (3), Sjöquist (37), Stewart (35), Woefel (45), Oker-Blom (18) and McClendon (16) stand out prominently. Their work was mostly concerned with the blood of animals and the eggs of shell fish. Osterhout (19-31), True and Bartlett (39-40), Dixon and Atkins (6-7), Stiles and Jörgensen (36), Bouyoucos (2), and others have entered the field from the botanical side. Bayliss has collected data on the hydrolysis of various proteids by the action of trypsin. He measured the increase in conductivity brought about by the reaction of the enzyme. Ziegel (46), van Suchtelen and Itano (41) have described electro-titrametric methods for determining the end point in reaction. Küster and Grüters (15) used the conductivity method as an indicator of neutrality in the titration of weak acids by strong bases. They also used the same method to determine the acidity of colored liquids where the color change of the indicator would be masked. Hall and Bell (8), and Patten and Robinson (32) working independently of each other applied the method of conductance to the determination of the neutrality of ammonium citrate solution. The work of Whitney and Means (44) and Davis and Bryan (4a) was along the line of developing a simple and efficient Wheatstone bridge that could be used in the field. This résumé of the literature does not claim to be exhaustive, the only purpose being to indicate the lines of study and direction of investigation.

Since the problems, which in all probability will lend themselves to solution through the aid of conductivity measurements, are numerous, and since so few have considered the results commensurate with the time, labor and patience in making a measurement, it is evident that any improvement of the old method will tend to enhance its value and lead the way to a clearer understanding of some of the little known biological problems. The old method, as has been admitted, is not free from many sources of error. It is not an easy matter to make a measurement and more time than ought to be necessary is consumed in making it. Besides the nerves of the operator are constantly under strain. With the changes suggested in the following pages, one is now able to obtain a high degree of precision with greater rapidity and much less strain on the nerves. The correct bridge setting is determined by the aid of the eye instead of the ear, a change which will no doubt greatly commend the method.

In the spring of 1913, by permission of the Director of the Experiment Station, a preliminary paper by the senior author (10) was published in the 15th report of the Michigan Academy of Science. Shortly before this, and while we were still working on the problems, there appeared in the February number of the Journal of the American Chemical Society a paper on "An Improved Apparatus for Measuring the Conductivity of Electrolytes," by E. W. Washburn and J. E. Bell (42). The method outlined in this paper was based upon three important changes in the customary apparatus. Working independently of these investigators, we made our changes along the same general line. However, our studies

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led us to introduce a still further change in the apparatus. The two systems differ radically in the type of detector used. We used the alternating current galvanometer, while Washburn and Bell still made use of the telephone, which they have, however, greatly improved.

The conductivity of a solution of any electrolyte is simply the reciprocal of its resistivity. The resistivity of that solution is usually measured by balancing it against a known standard resistance. The apparatus used is the well known Wheatstone Bridge. This is a network of six conductors represented in one of the following three forms all of which are equivalent. See Fig. 1. Like letters designate the same conductors and the same points of connections in all. In the text books of physical chemistry the sketches are more diagramatic usually taking the form represented in Fig. 2. The parts referring to the six conductors are

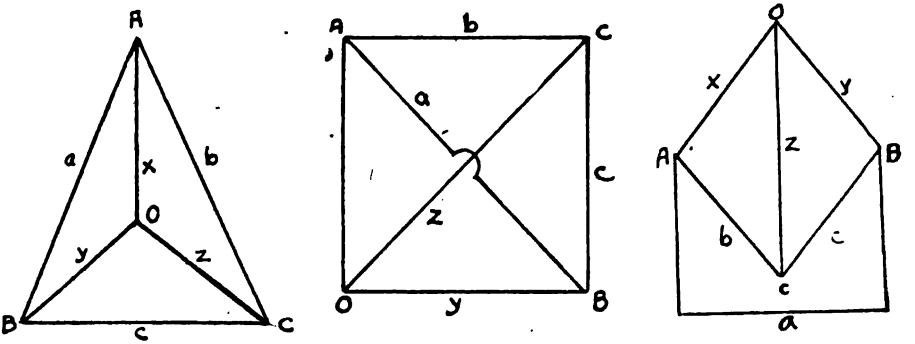


Fig. 1.
Conventional diagrams of the six conductors in a Wheatstone Bridge Network.

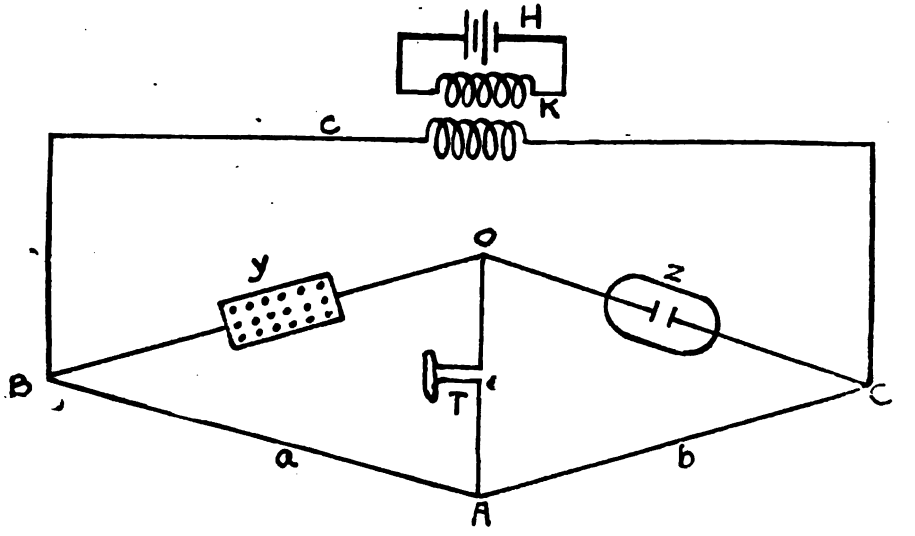


Fig. 2.
Conventional drawing of the parts of the Kohlrausch Setup. T, telephone; Z, electrolytic cell; Y, resistance; K, induction coil.

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lettered exactly as in Fig. 1. The letter H represents the battery which actuates the induction coil K. The known resistance or set of resistance coils is Y, the unknown resistance or the solution whose resistance is desired is Z. T is the telephone. At this place it is not necessary to go further into the theory of conductance measurements but merely to call attention to the fact that this network illustrates the "Null" method in which the quantity being measured is balanced against some other quantity and the point of equilibrum determined by means of a telephone. It is less rapid than the deflection method but on the other hand is much more accurate and there is less necessity for applying corrections. "Null" methods are generally to be preferred for all precision work.

The Wheatstone Bridge network described below is the outcome of a systematic study of the various sources of error in the ordinary method. We were led to such a study because of all the known methods for determining the resistance of electrolytes none proved suitable for the particular problem then under investigation. Not only were there certain errors that could and should be eliminated, but the method we thought could also be simplified and made rapid and easy. It has been assumed, in the case of dilute nutrient cultures that the external errors due to the nature of the experiment are greater than the errors due to the apparatus. If this is true it is hardly advisable to improve the apparatus. However, the methods of control can be greatly improved so that a corresponding improvement in the apparatus is welcomed. It is obviously better to control all the errors possible, whether of the apparatus or experimental technique, than to be satisfied to "let well enough alone." In addition to its value to the biologist this method can be used by the most exacting physical chemist. It has a precision ten times that of the Kohlrausch method, and the measurements can be made with ease and rapidity.

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## 2. CONSIDERATION OF THE SOURCES OF ERROR.

### SOURCE OF CURRENT.

All those who have had any experience with the usual method of determining the conductance of electrolytes will agree that of all the parts of the apparatus the induction coil gives the most trouble. It is continually getting out of adjustment. Sometimes this happens while a measurement is being made. Perhaps one of the larger more expensive coils is less apt to get out of order. These, however, are not as efficient as the small cheap ones because in the latter the current that passes at each pulse is small, and consequently, error from polarization is negligible. Again, in the small cheap induction coils the vibration of the "hammer" is rapid and the tone, therefore, is high-pitched and more readily audible in the telephone. A tone similar to the hum of a gnat is the most desirable.

There is a more serious trouble in the use of the induction coil than that mentioned above and for this reason it should be abandoned. The

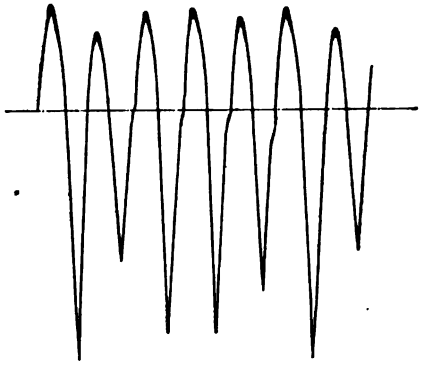

Fig. 3.
Curve from an oscillogram of an induction coil current. After E. W. Washburn. From page 10, catalogue 48, 1915, Leeds & Northrup Co.

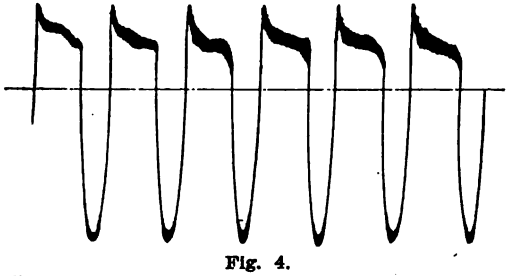

Fig. 4.
Curve from an oscillogram of an induction coil current when operating well. After E. W. Washburn. From page 10, catalog 48, 1915, Leeds & Northrup Co.

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coil does not give a current whose integral value is zero. In other words, the current is not alternating; merely pulsating and having a unidirectional component. This condition of affairs gives rise to polarization because of a counter e. m. f. and consequently a false reading. Altho we had assumed that such errors existed, and our assumption appeared justified, they had not been experimentally verified. Dr. Washburn, however, has recently shown by means of curves obtained from oscillograms, that these errors were present. Fig. 3 is a curve taken from an oscillogram of an induction coil current. It shows clearly that the current is not alternating. Fig. 4 represents the e. m. f. wave when the induction coil is operating well. By plotting the areas of the positive and negative loops with a suitable measuring device it will be seen that they are not equal, therefore the e. m. f. in one direction is greater than in the other and we have a unidirectional current. This same conclusion was reached by Dr. Washburn from another experiment. When the current from the secondary of an induction coil is passed through a silver coulometer a deposition of silver takes place, hence there is a polarization at the electrode and the current is unidirectional. The introduction of another electrolytic cell in the adjacent bridge arm has been suggested as a means of balancing out the polarization effect. This unfortunately does not correct the trouble because the cell itself is a source of error especially on account of the temperature uncertainties.

When used with the telephone the induction coil is not free from over tones and the frequency is not always constant for a sufficient length of time. If it should happen to maintain a constancy for a sufficient time it is apt to change in tone unexpectedly. Thus an improvement in the telephone, which recent work in wireless telegraphy has made possible would be of no advantage. Therefore, for precise work, the induction coil is not satisfactory.

The Siemens and Halske high frequency generator, in connection with the telephone, has been used, but this only produces an approximate sine wave even when operated on a current of constant potential. To protect it from varying loads and to detect such variations, quite an amount of auxiliary apparatus is necessary. A 110 volt generator to drive the machine; two mica condensers to vary the capacity of the circuit and distribute it symmetrically in respect to the generator; a device for detecting the frequency and to indicate when corrections should be made; two rheostats, one to control the speed of the motor and the other to vary the exciting current employed during a conductance measurement: and a hot wire ammeter to indicate the condition of the current, constitute the necessary apparatus. Such an array of apparatus will need constant care and watching to keep in good working order. It cannot be assembled in one place. The operation of certain parts interferes with the proper working of others. The generator because of the noise produced by the rapidly revolving toothed wheel must be put away in a room some distance from that in which the measurements are being made. The operator must be in a quiet place in order to determine the minimum tone through the telephone. This auxiliary apparatus costs in the neighborhood of $300 and if it constituted all that was necessary for determining a conductance measurement, an objection might not be forthcoming. This is, however, only a small part, and simply arranges for a current of constant potential to the bridge. Probably the best source of constant potential

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is the Vreeland Oscillator recently put on the market. It is the easiest to keep in running order and most convenient to handle. No condensers, frequency meters, hot wire ammeters, etc., are necessary. It is noiseless and therefore can be kept near the operator if need be. In addition, it has the great advantage of producing a pure sine wave. Even in the cheaper form, the price of this instrument is $225, and is obviously too much to lay out on one part of a Wheatstone Bridge network.

All these instruments give a frequency of 1,000 cycles per second. The use of a frequency of 60 cycles in conductance measurements of liquids will, in all probability, be viewed with suspicion, and we might also add that that was our earlier attitude. It is asserted that, working with such low frequencies, the results are liable to error from polarization. However, after the continued use of this frequency, in connection with a sensitive indicator and the control of certain other necessary conditions, over a period of two years, we believe that the difficulties assumed are more apparent than real. Let us consider the theory for a moment. We can assume that, for a very *small* current passing for a short time, the e. m. f. of polarization is proportional to the quantity of electricity which has passed through the cell. When measured by a balanced Wheatstone Bridge the resistance will increase with the time that the current is kept on and will always be higher than the true resistance. For this reason the use of the Wheatstone Bridge with *direct current* is not suited to the determination of the resistance of solutions of electrolytes. If, on the other hand, one uses alternating current and a sensitive detector the principle of the Wheatstone Bridge can be used with accuracy. This is so, quoting from Dr. Northrup (17), "because the e. m. f. of polarization, produced by the current in one direction, and which would lead to a balancing of the bridge giving too high a value of the resistance, will, upon the reversal of the current, either be neutralized or, if not neutralized, will lead to a balancing of the bridge giving too low a value of the resistance. Thus the setting actually obtained for a balance is the same whether polarization is neutralized or not, as would be required were there no polarization." A statement of this kind from such an authority should cause us to reconsider our ideas of the possible error from polarization.

It is a well known fact that the amount of hydrogen separated per square centimeter at the electrode is directly proportional to the current passing. By regulating the current so as to make it small, the amount of substance separated at the electrodes, or in other words the polarization can be made negligible. When the alternating current changes rapidly such as it will at a frequency of a thousand we are told that polarization is not likely to take place. There is not sufficient time for hydrogen to separate out before the phase is changed. At 60 cycles where more time elapses before the change to the other phase takes place it has been assumed that the hydrogen might possibly have time to diffuse into the solution and thus change the concentration. We are told that only under special conditions will the error from polarization be rendered small enough to permit measurements at 60 cycles per second. These statements above might lead one to believe that we have taken a lot for granted and accepted without reserve a lot of assumptions. In all our experiments we have not had any trouble from polarization which could not be eliminated. Because of the nature of the indicator we use it is not neces-

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sary to pass the current through the network or system for more than a second at a time and thus the chance for error from polarization is very slight if any. In addition, if one platinizes the electrodes well and then selects the proper form of conductivity cell for solutions of high or low resistance, as the case may be, there is little danger of error from polarization.

INDICATOR OR DETECTOR.

There are a number of instruments that have been used to determine when the solution whose resistance is desired, is balanced against the known resistance in a Wheatstone Bridge network. The one that has been used more than any other is the telephone. Recent advances in wireless telegraphy have had much to do with the improvement of the telephone. It is claimed by some to be the best detector, and because of the improvements made we have the probable reason for its continued use. For precise work the telephone with all its improvements must be used in an absolutely quiet room. An improvised telephone booth should be provided. The operator must also give his undivided attention to the work of listening. The strain on the nerves is severe. It is exceedingly hard even under these conditions to detect a "perfect minimum" or a point at which no sound is heard. To determine the exact point where a constant but gradually decreasing sound stops, is difficult. One often imagines he hears a sound when in reality he does not. A continual hum in the head often follows the operator to his recreation for some time after he has left the laboratory. Recently the senior author was told that this trouble in determining the "perfect minimum" was obviated by a certain attachment on the telephone which caused a series of interrupted noises. When these staccato sounds were not heard the balance had been reached. Up to the present time he has been unable to find any article describing the modified telephone but it appears very possible that such a change could be made. An improvement of this sort would be welcomed.

The telephone at its best is one that is "tuned" to the frequency of the exciting current and this is usually a thousand cycles per second. Even the best telephone, however, is not the best detector. There is a residual tone that cannot be eliminated and which is always present to interfere with the detection of the tone of the machine. The tones most evident in an alternating current are the upper partials, especially the upper third. One can modify the diaphragm of the telephone to eliminate this, but as one corrects one error, one falls into another. This correction would produce a sharp tuning curve and require too close a control of the frequency which in turn is difficult to maintain when there is any variation in the operating current. An extra equipment noted above has to be supplied. With the telephone as the detector a fairly close adherence to the frequency is necessary. A deviation of 100 cycles per second halves the sensitivity. The difficulties attending the use of the telephone outlined above led us to select an instrument which would not necessitate the use of the ear. Our best results were obtained with the Alternating Current Galvanometer with a mirror and scale. This is more satisfactory than the telephone in many respects.

Probably the two greatest factors which influence the sensitivity of any resistance measuring device are the constant of the detector and the magnitude of the current. In the latter case there are certain limitations

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which are dependent on the capacity and heating effects in the resistances, and in the former the limitations are only those that can be overcome. If it were not necessary, for example, to load a galvanometer system with a mirror for the purpose of reading a deflection, and if again the moment of inertia of the movable coils were as small as possible and if still further the coils were wound non-inductively and for the annulment of capacity, then the galvanometer would have a large figure of merit. Progress in galvanometer construction is being rapidly made, and it only rests with the future to produce an extremly sensitive apparatus. The use of a galvanometer of the dynamometer type as a detector for liquid resistances was suggested more than fifteen years ago by the late professor Rowland (34) of Johns Hopkins University. It is surprising to note that apparently little attention has been given to this suggestion. The following quotation is taken from his Physical Papers, page 294:

"I also give a few methods of resistance measurement more accurate than usually given by means of the telephones or electrodynamometers as usually used and especially suitable for resistances of electrolytic liquids"—"I have introduced here many new methods, depending upon adjusting two currents to a phase-difference of 90° which I believe to be a new principle. This I do by passing one current through the fixed coil and the other through the suspended coil of an electrodynamometer. By this means a heavy current can be passed through the fixed coils and a minute current through the movable coil, thus multiplying the sensitiveness possibly a thousand times over the zero current method." "Using non-inductive resistances, methods 10 and 14 are especially good and I have no doubt, will be of great value for liquid resistances. The liquid resistances must, however, be properly designed to avoid polarization errors." "Altogether the results of experiment justify me in claiming that these methods will take a prominent place in electrical measurements especially where fluid resistances, * * * are to be measured. The new method of measuring liquid resistances with alternating currents allows a tube of quite pure water a meter long and 6 mm. in diameter having a resistance of 10,000,000 ohms to be determined to one in a thousand or even one in ten thousand. The current passing through the water is very small, being at least 500 times less than that required when the bridge is used in the ordinary way. Hence polarization scarcely enters at all." We reproduce two of his figures below (Fig. 5). In these two methods the concentric circles are the coils of the electrodynamometer. Either one is the fixed coil and the other is the hanging coil. Oblong figures are the inductances and when near each other are mutual inductances. A pair of cross lines is a condenser. This quotation is given in full because of its bearing on the present work and to aid in counteracting the general notion that the telephone is good enough.

There have been several objections to the use of the dynamometer but none of these appear to have any foundation. It has been claimed that the most serious objection arises from the fact that the two currents might sometimes be in quadrature. In this case, though the bridge is unbalanced and a current is passing through the coils, there will be no deflection of the galvanometer scale. Should such a possible condition arise it could be eliminated by the introduction of a condenser to produce a "lead" in the current. In all our experiments we have never experienced this trouble and yet if it should arise we have a suitable means of controlling it.

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It has also been objected that the necessarily strong current in the coils to produce the greatest sensitivity would in turn produce such a load on the electrolytic solution as to exert a deleterious heating effect. This objection is not valid. Such a trouble can be obviated by introducing a variable resistance in the bridge circuit to control the amount of current to any strength desired. This heating effect is sometimes quite appreciable, and causes a very considerable error. It takes place in the more

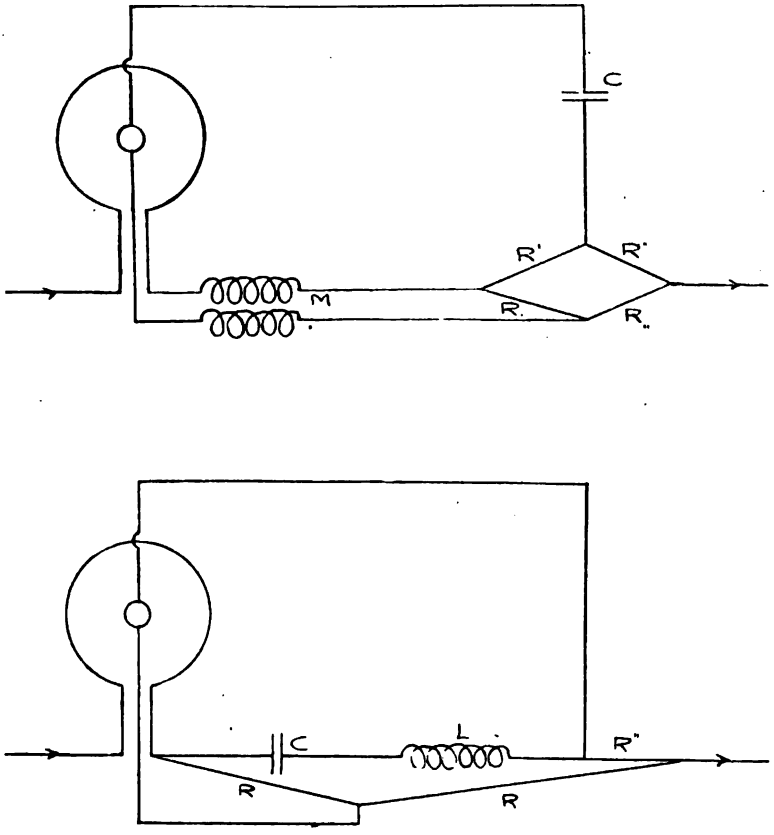


Fig. 5.
Diagram of connections when using an electrodynamometer. From Henry A. Rowland's Physical Papers, Figs. 10 and 14, page 302.

concentrated solutions. To determine the resistance of such solutions only a small amount of current is necessary. Cutting down the current does not decrease the sensitivity when working with such solutions. A paragraph from the works of Professor Rowland concerning the sensitivity of an electrodynamometer is quoted here:—"An electrodynamometer can be made to detect .0001 ampere without making the self inductance of the suspended coil more than .0007 henrys or that of the stationary coils more than .0006 henrys, the latter readily sustaining a current of 1/10 amperes without much heating." The point of balance is exact.

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The galvanometer has at least four advantages over the telephone. 1. The direction of the deflection indicates on which side the bridge is unbalanced and the exact balance can be made easily and quickly. On the other hand in the case of the telephone the sound increases equally without distinction for a departure from the setting of the resistance in either direction from that which gives a true balance. 2. When the current is put on, the direction of "creeping," if there is any, will indicate whether there is polarization or heating. This will quickly show where and how the changes in the system are to be made. 3. It is only necessary to close the switch for less than a second at a time when finding a balance. Consequently the possible error due to heating or polarization is negligible. When using a telephone the current is on all the time until the balance is found. 4. The eye is more accurate than the ear and even if the two instruments had the same figure of merit the one that makes use of the eye is preferable. The operator is not under a nervous strain even if he desires to attain an accuracy of .001 of 1%.

The galvanometer costs more than the telephone but it is a well known fact that in general, increased sensibility in the indicating device leads to a reduction in size and cost of all the rest of the equipment required.

## RESISTANCES.

The ordinary resistances and even the best grades of coils put out until recent years are not suitable when measuring the resistances of dilute solutions of electrolytes providing accurate results are desired. This is so because the coils are not free from capacity and inductance. These are the two great sources of error to be guarded against when using alternating currents. In a system like the Wheatstone Bridge every conductor has a capacity especially when it is surrounded by other conductors and this capacity can be defined as the ratio of the charge of the conductor to the potential produced by the charge. Its value is dependent on the form and dimension of the conductor and the nature of the dielectric. The electrolytic cell and the resistances act as capacities and vary with the current period. High resistance coils give the larger error. With resistance coils of 20,000 ohms or more, the power factor is large on account of the poor dielectric which the resistance contains. Consequently the capacity is large.

The general effect of capacity is to produce a "lead" in the phase and whenever the phase difference is large the currents are apt to be in quadrature and in this case though a current passes through, no deflection of the galvanometer scale is produced. Therefore correct resistance values can only be obtained by meeting the condition that the four arms of the bridge are without appreciable capacity and inductance. The new resistance coils are now wound to avoid capacity and inductance. The capacity of the electrolytic cells is eliminated by introducing a condenser of proper value. Kohlrausch (14) drew attention to this matter some time ago, but it is only in recent years that our knowledge of condensers has sufficiently advanced to develop one that is efficient. The coils in the bridge should also be wound to avoid capacity and inductance.

The effect of unbalanced capacity is to make the "balance point" less precise. The "balance point" is taken as that point where there is no deflection. This means that the unknown solution in the cup just balances the known resistance. This definition further assumes that a move-

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ment of the bridge, in either direction, as much as a tenth of a scale division should cause a deflection in the galvanometer scale. Under some conditions the range may extend a number of scale divisions before deflection occurs. Thus only an approximate value is obtained and the reading is not precise. By using a condenser this error can be corrected to a certain extent, but it is far better to avoid the use of condensers and use resistances which have no capacity.

Again capacity effects increase with the frequency and soon produce heating which will raise the true resistance value and thus introduce an error. At a frequency of a thousand cycles per second the current does not flow equally through the cross section of the conductor but is confined mainly to its outer surface. Consequently when the current is not distributed equally heating results and the resistance rises and there is a false reading.

By using alternating currents the errors from self inductance are greatly increased. With direct current self inductance only occurs at the making and breaking of the circuit. Alternating currents are not only passing forward and backward, but are rising and falling in value and such changes in a conductor will induce in it a counter e. m. f. This self-induced e. m. f. will be in such a direction as to oppose the change of current which it produced. The amount of self inductance is dependent on the rate of change in the current. Obviously alternating currents, and these at a high frequency introduce a great error. These can all be eliminated by using resistances wound non-inductively. The new Curtis resistance coils are such, and they are the only suitable ones for electrolytic measurements.

### RESISTANCE CELLS.

The solutions or living plant or animal tissues to be studied, are placed in certain resistance cups or cells. The form, shape and size of both the cups and the electrodes are matters of importance. The accuracy of a measurement is dependent to a great extent upon the design of the cell. Freedom from impurities must be assured. The construction of the various parts must not be lightly considered. There are a number of factors, which make it necessary to construct resistance cells of various forms. In regard to solutions, one particular form is not suitable for concentrated and dilute solutions alike. The form of the cell is dependent upon the size and shape of the electrodes and upon the distance these are apart. In turn the nature of the solutions controls the size and shape of the electrodes and the distance they should be apart. For convenience these cells have been grouped according to the purpose they serve. 1. Resistance cups for good conducting fluids. 2. Resistance cups for poor conducting fluids. Several different forms are figured in the publication of Kohlrausch and Holborn (14) and recently new forms by Prof. Washburn are pictured in catalogue No. 48 of the Leeds & Northrup Company. The Fritz Kohler catalogue for 1909 also shows a number of forms.

The electrodes are usually circular in form and consequently the resistance desired is the resistance of a cylinder of liquid enclosed between them. This cylinder is modified greatly by either varying the distance between the electrodes or increasing the surface of the electrodes. As a general rule, it may be said that the electrodes must have a large surface and be close together when the solution to be measured is "conductivity-

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water" or a solution which is extremely dilute in respect to its solute content. Conversely it follows that the electrodes must be far apart and the surface small, if one wishes to measure the resistance of concentrated solutions. In the former case, conditions are such as to favor the passage of a strong current, while in the latter a weaker current is allowed to pass and a further hindrance to its passage is effected by increasing the distance through which it is required to pass.

It is necessary that the platinum be of the best quality and free from lead and calcium. Also it must be stiff enough so as not to change shape or get out of position. Otherwise the cell constant would vary and introduce a source of error. Certain modifications of the cell and its electrodes have much to do with the control of error from polarization. Platinized electrodes increase the surface enormously. Kohlrausch estimated that a coating of platinum black increased the surface a thousand times. With electrodes of such large surfaces polarization is negligible. Platinum black absorbs the gas as soon as it is separated out and it does not therefore modify the concentration of the solution. The statement has been made that it is unnecessary to platinize electrodes. From our experience with a frequency of 60 cycles per second we obtain better results with platinized electrodes than with bright electrodes. It has been argued that bright electrodes are preferable since platinized electrodes cannot be used in all cases. Platinum black acts as a catalytic agent under certain conditions and will bring about chemical reactions. A proper selection of the solution or a modification of the electrodes will obviate this difficulty. Again, on account of the spongy nature of platinum black, it is argued that it will absorb some of the electrolyte, and when the same cell is used for another solution of different concentration or character, it will cause an error in the measurement. By taking a new clean cell, or by cleaning the old one this trouble can be corrected.

Another factor in regard to the construction of resistance cells must be kept in mind. There must be the smallest amount of space possible between the lateral edge of the electrodes and the glass walls of the electrolytic cup. When working with nutrient culture solutions in different sized beakers a new form of electrolytic cells is used. This is called the "plunger" cell. The electrodes are enclosed in a cylindrical glass chamber and always maintain the same position in reference to the side walls of the chamber. The chamber is pierced at the bottom and top by three holes. When this is plunged into the liquid in the beakers the solution passes through the holes and surrounds the electrodes. When everything is at rest a measurement can be made. When measuring the resistance of living or dead tissue another form is required. This must be made mechanically rigid and allow for an arrangement whereby the tissues can be securely and firmly clamped between the electrodes. This form is one devised particularly for work with tissues and is figured in this paper.

## SUMMARY.

The following conclusions can be drawn from a consideration of what has been said concerning the sources of error in the usual Wheatstone Bridge set up. The induction coil as a source of current must be abandoned. The telephone is not as sensitive as the alternating current galvanometer of the dynamometer type. The common resistance coils are

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not suitable for work of precision and must be replaced by the Curtis Coils which are wound to avoid inductance and capacity. The resistance cups must be selected according to certain necessary conditions. A condenser must be used across the resistance to balance out the capacity in the electrolytic cell. In the following pages we describe the apparatus we have been using and then add the results of a few tests to show the precision which this method attains.

## 3. THE SIMPLIFIED RESISTANCE MEASURING APPARATUS.

When working with electrical instruments, or a resistance measuring network like the Wheatstone Bridge it is a good plan, on general principles, to select the apparatus so that its various parts are in conformity. It is therefore necessary to know the various pieces and to be able to judge as to the relative value of things. It is obviously wrong to use a poor grade low resistance and a moderately sensitive detector if one desires to measure conductivity water. There are other arrangements which should be condemned, but yet are not so apparently wrong as in the above illustration. Each part should be selected and arranged to conform to certain demands in other parts. In the usual method the stationary coils and the swinging coils of the dynamometer have been connected in series. The better way and one in which the sensibility is increased nearly 1,000 times is to connect the swinging coils across the bridge and place the stationary coils in the main circuit. We believe, after working for some time with all the old and the most recent devices for measuring the conductivity of electrolytes, that we have now brought together a simplified, accurate and efficient apparatus. Fig. 6 shows the arrangement and scheme of connections for the new apparatus. Fig. 7 represents the apparatus all assembled ready for a measurement.

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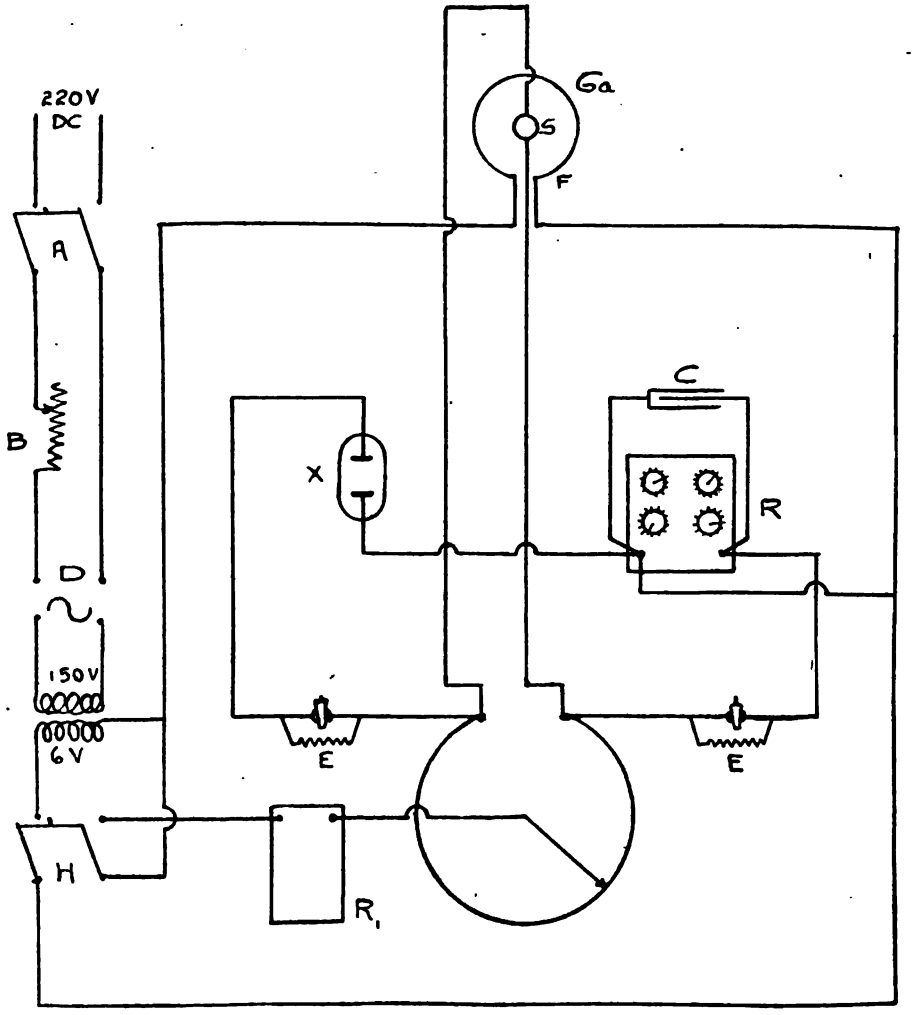


Fig. 6.
Scheme of connections of the apparatus used in this paper.

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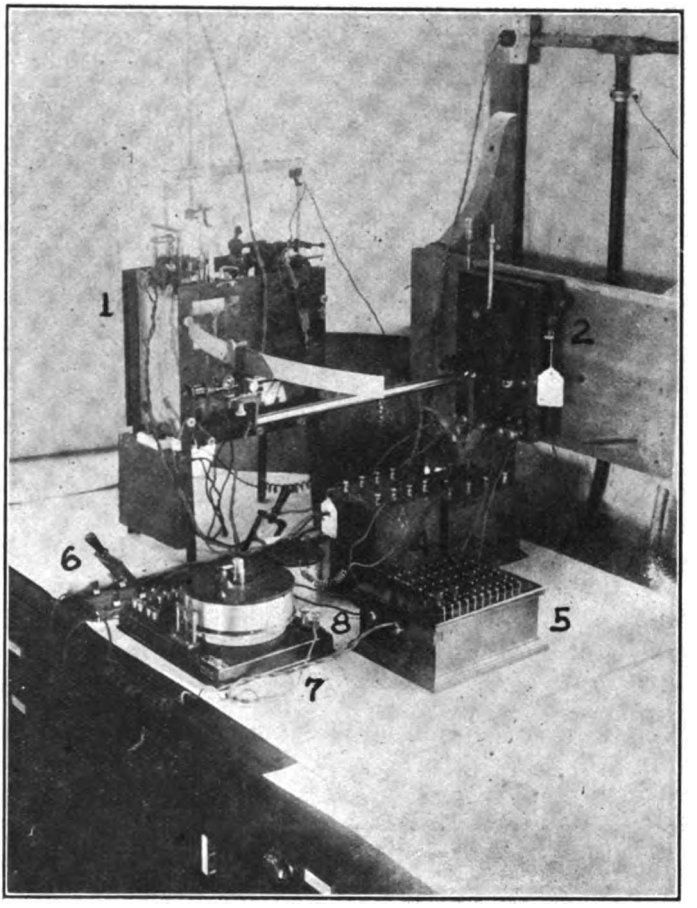


Fig. 7.
Complete Setup.
1. Bath. 2. Galvanometer. 3 and 4. Curtis Coils. 5. Decade Resistance in bridge circuit. 6. Switch controlling bridge and galvanometer circuit. 7. Bridge. 8. Condenser.

## SOURCE OF CURRENT.

The source of current is a 60 cycle rotary converter. The first converter used was a large stationary type run on a constant potential of 110 volts from an Edison storage battery. The first studies were made in the electrical power laboratory of the physics department. Later work was done in the botanical laboratory and the current derived from a small portable 1/10 horse power, 60 cycle, rotary converter. (Fig. 8). This was obtained from the Holtzer Cabot Electric Company of Boston. It proved very satisfactory. A variable transformer was used in connection with this converter to cut the current down to 6 volts. This was then connected with the bridge circuit and the stationary coils of the gal-



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vanometer circuit without further change. In a previous part of this paper reasons were given to show that no errors but what could be corrected could arise from the use of this frequency. The converter and its transformer were stored away under the table and kept from the galvanometer so that the latter would not be exposed to any external electric field. Underneath and at the side of the table within easy reach of the operator a switch and starting box was placed. It was deemed advisable to use a starting box so as to avoid any injury to the rotary converter through overloading.

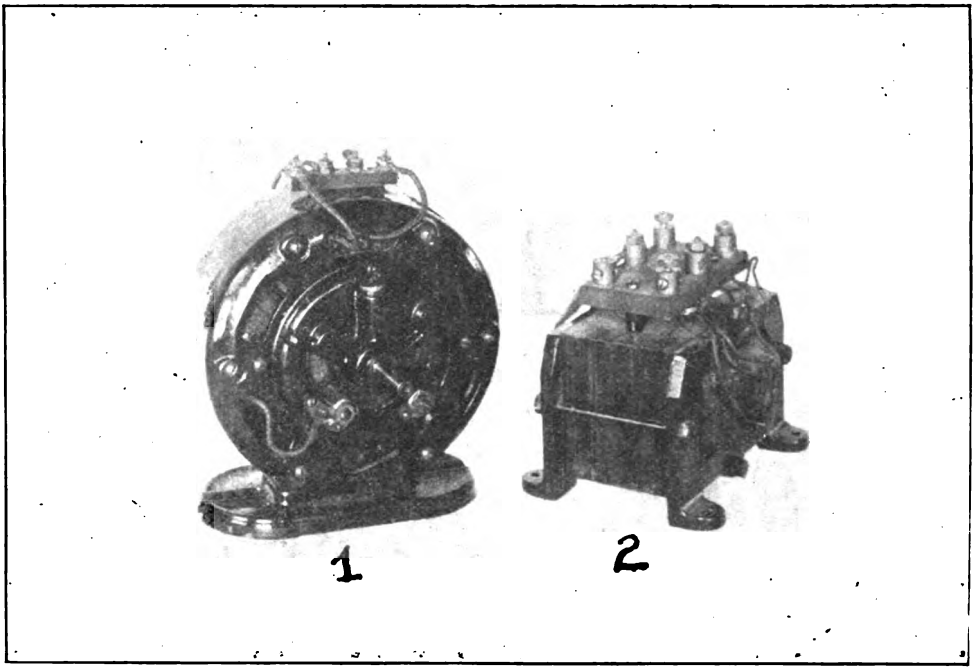


Fig. 8.
Source of alternating current. 1. Rotary converter. 2. Transformer.

DETECTOR.

The instrument used to determine when a balance had been found was an alternating current galvanometer of the electrodynamometer type, first suggested by Prof. Rowland in 1897. This galvanometer was made by the Leeds & Northrup Company and has proven very satisfactory. Fig. 9 shows the scheme of connections. The fixed coil of the galvanometer is placed in the main circuit to increase the sensibility of the apparatus. The swinging coil is connected across the bridge in the same manner as with the telephone in the Kohlrausch method. The resistance of the fixed coil is 29.8 ohms and the maximum allowable current is 1/5 of an ampere for 10 second periods. By throwing on the 6 volts from the transformer this value of the current is just reached. The resistance of the swinging coil is 21.8 ohms and the maximum allowable current is

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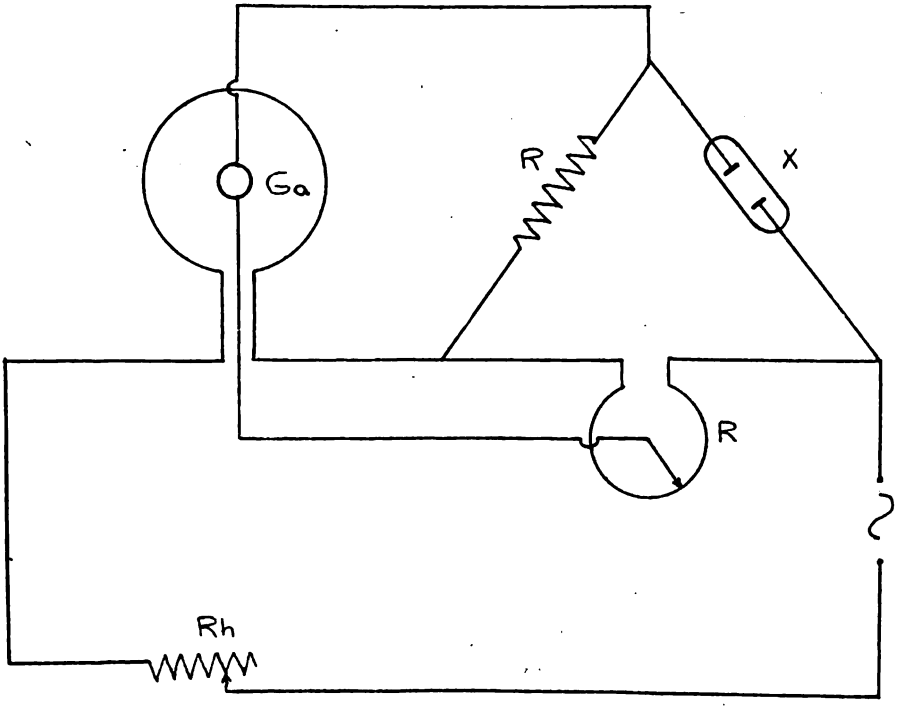


Fig. 9.
Scheme of connections when a galvanometer is used in the Wheatstone Bridge network.

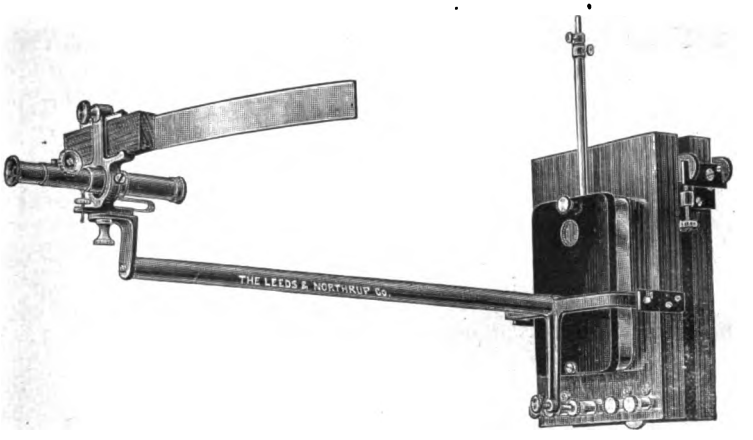


Fig. 10.
Detector. An alternating current galvanometer.

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1/10 of an ampere for 10 second periods. Fig. 10 is a cut of the alternating current galvanometer used in these experiments.

When a galvanometer of the moving coil type is used, precautions must be taken against exterior electric fields. All such parts as produce this trouble should be incased in metal tubing or placed below the table. Until this was done the galvanometer scale was deflected as much as a scale division. This means an error of .1 of 1%. The data that accompanied the galvanometer make no mention of its sensitivity except when the stationary coil is so connected as to be in series with the swinging

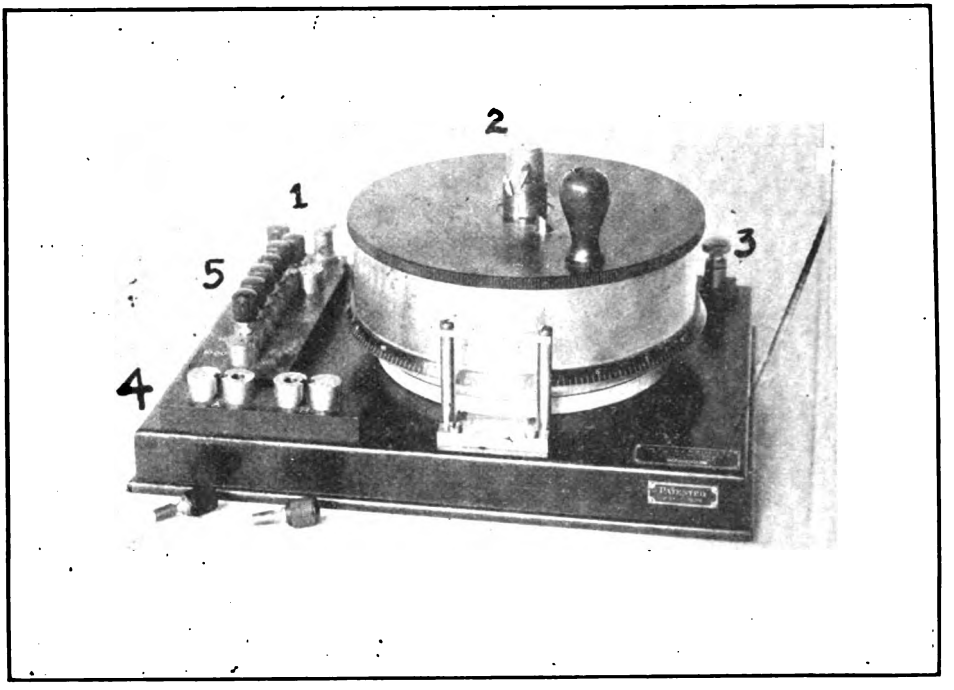


Fig. 11.
Bridge.

1. Posts for leads to electrolytic cell.
2. Posts behind drum for galvanometer leads.
3. Battery post.
4. Extension wire posts. "Extension" represented as in.
5. Resistance in bridge base. Disconnected.

coil. Under this condition the sensitivity is .0027 amperes at 100 mm. Connected up in the other way the sensitivity is probably of the following order .000027 at 100 mm. A double contact switch on the top of the table and near the operator controls the galvanometer and bridge circuits. The circuit can be made and broken as the conditions require. It is never left on for more than a minute and usually only for a second or less. As soon as a deflection is noticed the circuit is broken and an adjustment of the bridge made. The circuit is again closed and the deflections of the scale observed. This operation is repeated until a balance is obtained. By this means errors from heating and polarization are elimin-

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ated. The connections on the double contact switch should be made so as to close the bridge circuit first and then the galvanometer circuit. A bottle of damping fluid is supplied with the instrument. Enough of this fluid is placed in the glass receptacle to cover the mica vane. The instrument is thus made aperiodic coming back to zero rapidly without over shooting.

### BRIDGE.

The bridge, Fig. 11, is also made by the Leeds & Northrup Company. It is the latest improvement of the roller type. Kohlrausch (14) early showed that if an accuracy of .05 of 1% is desired the bridge wire would have to be extended. Two coils, non-inductively wound, each of which has a resistance of 4½ times that of the bridge wire itself, were placed at opposite ends of the wire. This constitutes the "extended bridge." The coils were so mounted on the bridge that by the removal of a couple of plugs the extension coils could be connected in. The rheostat coils usually found on this type of bridge were disconnected to avoid any error from capacity and inductance. The bridge has ten turns of wire upon its drum with a resistance of 7.157 ohms. Each extension has a value of 32.2 ohms thus making the resistance of the bridge wire and its extensions 71.557 ohms. A wire of low resistance and larger cross section is preferable to one that is very slight and slender because its calibration will remain more nearly constant. In addition it will stand wear and heavy treatment better.

There are a thousand scale divisions on the bridge and each one of these is divided into halves, making a scale of two thousand parts. Each of the smallest scale divisions is 3 mm. wide, and the bridge reading can be made to 1/5 part of this division without much difficulty. The error from a bridge reading will not be more than .002 of 1%.

The alternating current was first passed through a variable resistance in series with the bridge and then connected to the slider. The resistance was introduced in order to vary the current, for when the more concentrated solutions are used much less current is needed. If the full current was passed through, the heating of the electrolyte would follow, and result in a false reading on the bridge. The resistance is connected on one arm of the bridge and the electrolytic cell in the other. The swinging coils are placed across the bridge.

### RESISTANCES.

The known resistances must of necessity be the best obtainable. These are the new Curtis Coils (Fig. 12). Their use was suggested to us after reading the article by Dr. Curtis (4) in a publication of the U. S. Bureau of Standards. According to a new method of winding the self-inductance and capacity of the coils are anulled. By request the Leeds & Northrup Company made for us a number of such coils of different values and assembled them in a box. Two of these boxes have been used in the experiments described in this paper. In assembling the coils in box form, it should be remembered that it is necessary to keep them sufficiently far apart to avoid any error from capacity. The newer "dial decade type" is more convenient and has a range of from 1 to over 100,000 ohms. A variable condenser (Fig. 12) must be introduced across the resistance to

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balance out the capacity in the electrolytic cup. This condenser must be chosen with a view to avoiding any leakage and therefore its insulation must be sufficiently high. An error of .2 of 1% is apt to occur from this cause. In making a measurement, take as much care to balance the capacities as you do to balance the resistances.

### ELECTROLYTIC CELLS.

The cells used in these experiments were of different forms depending upon the purpose for which they were to be used. The materials from

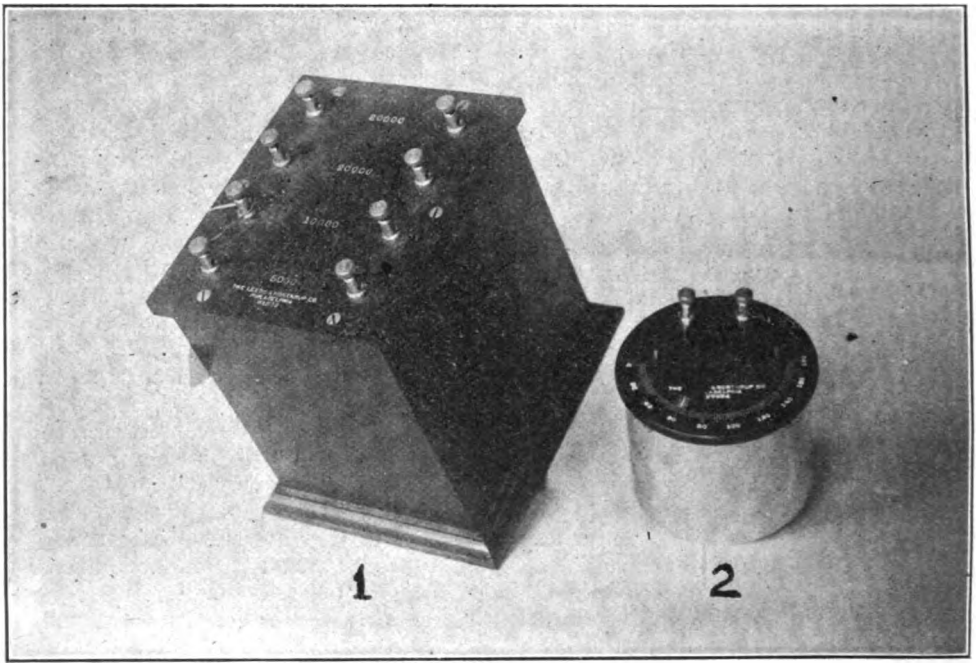


Fig. 12.

1. Resistance box. Curtis Coils.
2. Condenser.

which they were made were Jena glass, hard vulcanite rubber, and platinum. Jena glass was chosen because it is one of the least soluble of all makes of glass. The slightest impurity from the glass or air causes an error in the resistance of the solution. The glassware was thoroughly cleaned by soaking it in a hot solution of potassium dichromate in sulphuric acid and afterwards rinsed in distilled water. The final treatment consisted in a steaming process for a few hours. "Conductivity water" showed no change in resistance after staying in cups prepared as above for a period of at least twenty-four hours. The hard vulcanite rubber parts were kept clean. The platinum was at least .35 mm. thick and rigidly fused to the glass connections. This prevented any change in the cell constant which would happen if the electrodes were in any way

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dislodged from their original position in reference to each other and the sides of the glass container.

Platinized electrodes were used in all the tests and the platinizing was according to the usual method (5). When the electrodes receive a coat of platinum black their surfaces are immensely increased and polarization is negligible. The electrodes were frequently cleaned and replatinized. Dr. Clark of the University of Illinois has suggested that the cleaning process can be greatly facilitated by placing the electrodes in Aqua Regia with a reversal of the current every minute. It takes only a few minutes to clean them thoroughly. When not in use the electrodes are kept in

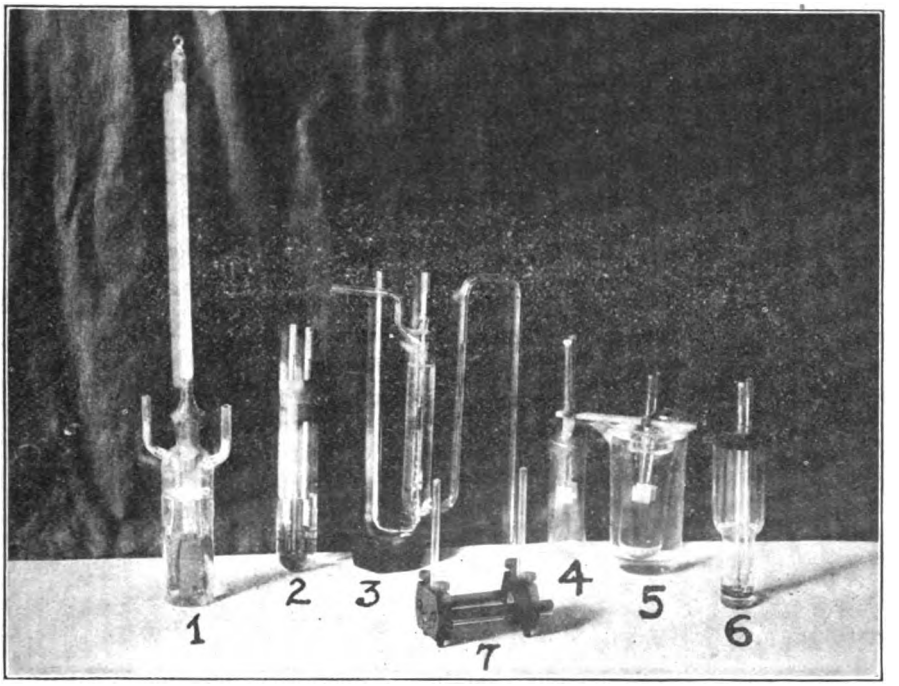


**Fig. 18.**
Resistance Cells.
Explanation of different types in text.

conductivity water (about $2.0 \times 10^{-6}$). Before using the cells, they are tested for constancy and when two successive readings of conductivity water give the same figures, the cells are considered in proper condition to use.

The various forms are shown in Fig. 13, Nos. 1, 4 and 5 are for solutions of low conductivity and Nos. 3 and 6 for high conductivity and No. 2 for medium conductivity. Nos. 4 and 5 are the plunger types to be used to determine the resistance of solutions in any size or form of beaker. This type eliminates the side effects. No. 7 is used when it is desired to measure the resistance of living tissues. Discs of the living tissues are pre-

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pared by using a cork-borer or other suitable device. These discs are then piled one upon another like a pile of pennies and clamped firmly between the electrodes. The pipette forms are similar to those figured in a paper by Washburn and MacInnes (43). It is preferable to have the electrodes vertical rather than horizontal for the quick removal of heat. It is advisable to immerse the bridge leads in tubes containing mercury, these tubes to be immersed in the bath so as to be at the same temperature as the cell. This reduces the passage of heat between the room and the cell.

### THERMOSTAT.

The conductivity of a solution is greatly affected by temperature changes. A variation of one degree gives an error of 2% in the readings. It is necessary therefore to keep the temperature constant during conductivity measurements. For accurate measurements, a variation of .01 of a degree C. is not permissible. The best thermostat contains a large body of water to reduce the effect of temperature changes of the surrounding bodies. This water must be kept in constant motion and at a constant temperature.

Various devices for automatically regulating temperature have been tried. The really efficient one is electrical. The electrolytic cells are suspended in the bath and allowed to remain so for at least 10 minutes before a measurement is taken. Then the resistance, that is to balance the solution to be tested is adjusted, approximately. The bridge wire can be used alone or in combination with the "extensions." For accurate work the "extended wire" must be used. A modification of the Ostwald thermostat was used for preliminary work. This only kept the temperature constant to within a .1 of a degree. For accurate work the Freas water thermostat may be used. In this one the temperature is kept constant to .002 of a degree. A Beckmann thermometer should be suspended in any water bath as a check on the thermostat. The temperature of the bath was kept constant at 18° C.

## 4. METHOD OF OPERATION.

The following method of operation is suggested. See that the bath temperature is correct and constant. Select the cell that will be best suited for measuring the solution in question. Fill the cell and suspend it in the thermostat. When the solution is at the temperature of the bath a measurement may be made. Now start the rotary converter, being sure that the double contact switch which closes the bridge and galvanometer circuits is open. Throw in 500 or 1,000 ohms resistance in the variable rheostat so as to cut down the current entering the bridge. This will prevent excessive deflection of the galvanometer scale. Observe the zero point on the galvanometer scale and then close the galvanometer and bridge circuit switch for an instant. Note the direction of deflection. This will indicate whether the known resistance is too high or too low. Adjust the resistance to suit condition and close switch again. Repeat operation until balance is approximately obtained. Now vary the cur-

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rent on the bridge by adjusting the variable resistance until a maximum sensibility is obtained. At the same time adjust the condenser to balance out the capacity of the cup. Carefully adjust all three, the current, the resistance and the condenser and make a careful reading. Make another filling of the cell and repeat operations until checks are obtained.

## 5. EXPERIMENTAL.

The apparatus we have assembled is not only less tedious or trying to operate but shows a high degree of precision. We note below the data on a few experiments. It is not necessary at this time to publish at further length, for in this paper we wish only to describe the apparatus and its method of operation and draw attention to its applicability to biological problems and reserve for a future publication the experiments for which this apparatus was primarily devised.

*Experiment I.*

The object of this experiment is to show the precision that can be obtained when using certain values of known resistances, balanced against each other. The new Curtis Coils were used. In the table below one set of coils is designated as A and the other as B. The "perfect balance" is defined as that point at which the galvanometer scale does not move. Now if the bridge is moved .1 of a scale division either side of this point, a deflection of the galvanometer is seen. A tenth of a scale division is selected, as this is about the smallest deviation which can be estimated without the use of a micrometer screw, and magnifying glass. The "extended" E and "short" S bridge wires were used. The former is used when an accuracy of more than .05 per cent is desired. The latter is sufficient for all tests of culture solution.

GALVANOMETER METHOD.

| No. of test. | Res. A. | Res. B. | Bridge. | Range. |
|---|---|---|---|---|
| 1 | 5000 | 5000 | S | Perfect balance. |
| | 5000 | 5000 | E | Perfect balance. |
| 2 | 10000 | 10000 | S | .2 scale division. |
| | 10000 | 10000 | E | .3 scale division. |
| 3 | 20000 | 20000 | S | .4 scale division. |
| | 20000 | 20000 | E | .5 scale division. |
| 4 | 35000 | 35000 | S | .7 scale division. |
| | 35000 | 35000 | E | .8 scale division. |
| 5 | 55000 | 55000 | S | 1.0 scale division. |
| | 55000 | 55000 | E | 2.25 scale division. |

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*Experiment II.*

The object of this experiment is to show the precision that can be obtained while using varying concentrations of KCl. The readings were made by one person.

*A.* Sol. M/10 KCl., E. Bridge, T. 18° C., Known Res. 26.6 ohms., Res. on bridge circuit 1,000. Conductivity cell No. II, electrodes platinized and 10 mm. apart.

| No. reading | Res. ohms. | Bridge reading. |
|---|---|---|
| 1 | 26.6 | 506.8 |
| 2 | 26.6 | 506.7 |
| 3 | 26.6 | 506.8 |
| 4 | 26.6 | 506.8 |

A "perfect balance" was obtained. In only one case was the reading .1 less than the others.

*B.* Sol. M/50 KCl, E. Bridge, T. 18° C., Known Res. 61 ohms., Resistance on bridge circuit 1,000 ohms. Conductivity cell No. I, electrodes platinized and 5 mm. apart.

| No. reading | Res. ohms. | Bridge reading. |
|---|---|---|
| 1 | 61 | 504.7 |
| 2 | 61 | 504.7 |
| 3 | 61 | 504.7 |

A "perfect balance" was obtained. No deviation.

*C.* Sol. M/1,000 KCl, E. Bridge, T. 18° C. Known Res. 1, 191 ohms., Res. on bridge circuit 400 ohms. Conductivity cell No. III, electrodes platinized and 6 mm. apart.

| No. reading | Res. ohms. | Bridge reading. |
|---|---|---|
| 1 | 1191 | 502.60 |
| 2 | 1191 | 502.60 |
| 3 | 1191 | 502.70 |

A "perfect balance" was obtained.

*D.* Sol. — twice distilled water, E. Bridge, T. 18° C., Known Res. 33,600 ohms. Resistance in bridge circuit, "out." Conductivity cup X, electrodes platinized and 2 mm. apart.

| | | Bridge reading. | | |
|---|---|---|---|---|
| No. reading | Res. in ohms. | Left | Middle | Right |
| 1 | 33,600 | 502.5 | 503. | 503.5 |
| 2 | 33.600 | 502.5 | 503. | 503.5 |
| 3 | 33,600 | 502.5 | 503. | 503.5 |

Range of 1 scale division or .5 scale divisions on either side before deflection took place.

*E.* Conductivity water having a specific conductance of $1.7 \times 10^{-6}$ ohms. at temperature of 18° C., E. Bridge, T. 18° C., Known Resistance 85,000 ohms. Res. in bridge circuit "out." Conductivity cup X. Electrodes platinized and 2 mm. apart.

| | | Bridge reading. | | |
|---|---|---|---|---|
| No. reading | Res. in ohms. | Left | Middle | Right |
| 1 | 85,000 | 497. | 498.5 | 500. |

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Range of 3 scale divisions. Reading was made quickly. The switch was closed for only an instant at a time. This precaution was necessary as the thin film of solution between the electrodes was exposed to a heating effect of the current. By allowing the current to pass for only an instant the heating effect was found to be negligible.

*Experiment III.*

In D and E of the preceding experiment the range of scale divisions is 1 in one case and 3 in the other. For solutions of high resistance these

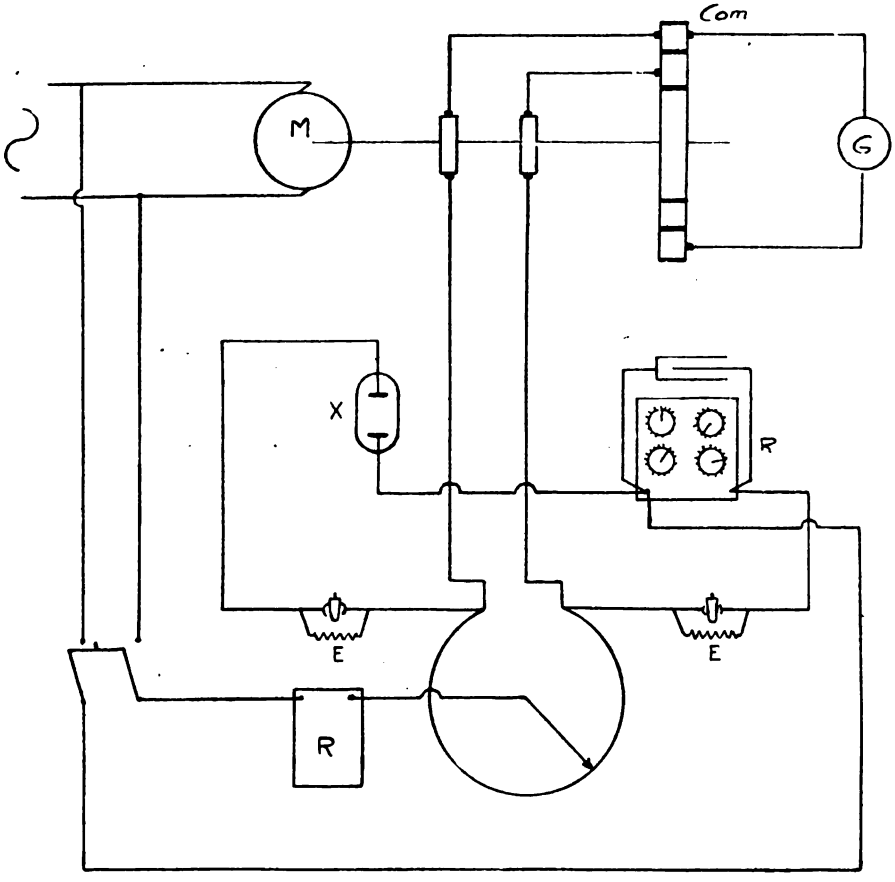


Fig. 14.
Arrangement and connection of parts when a D. C. galvanometer and rectifier are used.

results may be considered very good. An experiment was made however to see if the range could be shortened.

It is a well known fact that a D. C. galvanometer is more sensitive than an A. C. galvanometer, but the former cannot be used with alternating currents. If, in some way, the alternating current can be rectified so as to become unidirectional then a D. C. galvanometer can be used. This change in current can be brought about by cutting out one of the phases

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of an alternating current. Devices that accomplish this are usually called rectifiers. There are a number of different forms but the most satisfactory one for this particular condition is the commutator. This is fastened upon the shaft of the rotary converter. Before an experiment is made this commutator is so adjusted as to eliminate one phase entirely. This adjustment must be made accurately as the value of all the work which follows is dependent upon it. The brushes must also be kept clean. Care in the above matters is necessary if the best results are to be obtained. Fig. 14 shows the set-up of the apparatus when the commutator and D. C. galvanometer are used.

For this experiment a water of rather low conductivity was selected. The resistance of this was determined by both the A. C. galvanometer method and the device which has just been described. The comparison is made from the standpoint of the range of scale divisions necessary for a reading.

*A.* Sol. Water of rather low conductivity, E. Bridge, T. 18° C., Known resistance 51,100 ohms. Resistance in bridge circuit "out." Conductivity cup X, electrodes platinized and 2 mm. apart.

| | Bridge Reading | | | |
|---|---|---|---|---|
| Method | Left | Middle | Right | Range |
| A. C. Galv..... | 500. | 501.125 | 502.25 | 2.25 |
| D. C. Galv. and commutator | 509. | 509.4 | 509.75 | .75 |

This shows that the use of a D. C. galvanometer and commutator shortens the range of scale divisions and makes the reading more precise.

The condenser at hand, where this work was done, did not possess a low enough capacity. If a suitable condenser had been at hand the range of scale divisions would in all probability have been smaller.

*B.* Sol. M/50 KCl, E. Bridge, T. 18° C., Known Res. 55 ohms. Res. in bridge circuit unknown. A rheostat not graduated was used. Conductivity cup I, electrodes platinized and 5 mm. apart.

| No. of reading | Bridge reading | Range |
|---|---|---|
| 1 | 493 | Perfect balance |
| 2 | 493 | Perfect balance |
| 3 | 493 | Perfect balance |

The heating effect was completely eliminated by placing a variable resistance in the bridge circuit.

*Experiment IV.*

This experiment is reported in order to demonstrate the presence of heating effect, when the current load on the electrolyte is heavy. It also shows how effectively it is eliminated by introducing a resistance in the bridge circuit.

The solution was M/100 KCl, E. Bridge, T. 18° C., Known Res. 100 ohms, The conductivity cup with ground-in thermometer was similar to that of figure 2 pictured on page 14, Leitvermögen der Elektrolyte, by Kohlrausch and Holborn. The electrodes were platinized but the distance between them was not determined. The form was that of a hollow cylinder. The bath thermometer was a standard one with Reichsanstalt cer-

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tificate and was graduated to tenths of a degree. The thermometer in the conductivity cup was graduated to tenths of a degree, but its accuracy is unknown. Since only relative changes are to be shown here extreme accuracy in temperature is not necessary. When the temperature of the bath was 18° C., that of the cup was 18.2° C. making a variation of .2 of a degree. The apparatus was first adjusted with the resistance in the bridge circuit and after a balance had been obtained the current was increased by a removal of the resistance. Immediately the scale deflected in one direction and gradually continued in the same direction. When the deflection reached the end of the scale the current was cut off and the time taken by a stop watch and the rise in temperature of the electrolyte noted. As an average of five tests the end of the scale was reached in 52 seconds and the temperature in that time had risen .8°. It may be mentioned here that when a resistance of 1,000 ohms was in the bridge circuit and the key down two minutes there was no deflection or "creeping" showing that the heating had been effectively eliminated.

The next two experiments are added in order to show the applicability of the conductivity apparatus described in the present paper to biological problems. As before, the intention is not to list a great number of experiments nor explain any in great detail. The method devised in this paper is adaptable to precise and delicate measurement of various biological phenomena.

*Experiment V.*

True (38) has shown that the resistance of distilled water decreases when seedlings of lupines or peas are grown in it, and attributes the fall of resistance to the excretion of electrolytes from the roots. His experiments touching on this point were repeated and confirmed.

Distilled water was used as a culture solution. This was put into thoroughly cleaned Jena glass beakers of 250 cc. capacity. The quantity of distilled water used in the beaker was 200 cc. Seedlings of Lupinus albus were used as indicators. The seeds were first soaked in the same water for about 16 hours, then adjusted on paraffined wire hooks which were hung from the edges of the beaker. The seeds were so adjusted that the hypocotyl would, on growing, reach the water in a vertical position. The beaker was covered with a glass plate so that moist conditions could be maintained. When the roots had reached the length of about 2 cm. the experiment was started. The seedlings while on the hooks were removed from this improvised germinator, washed thoroughly in fresh conductivity water and then suspended in the culture dishes. At the same time the electrodes were plunged into the solution and a reading made.

At 3 P. M. 3/13/15 the resistance was 29,595 ohms.
At 9:30 P. M. 3/13/15 the resistance was 24,945 ohms.
At 9 A. M. 3/14/15 the resistance was 19,393 ohms.
At 7:30 P. M. 3/14/15 the resistance was 16,125 ohms.
At 8:40 A. M. 3/15/15 the resistance was 15,210 ohms.
At 3:30 P. M. 3/15/15 the resistance was 13,735 ohms.

This experiment shows that the excretion of electrolytes was more rapid and in larger quantities at the beginning than at the end of the given

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period. It also shows that during a period of a little over 48 hours the resistance had fallen from 29,595 ohms to 13,735 ohms.

It is instructive to compare these results with the results obtained when tap water is the culture solution. The experiment is the same as the preceding in every respect except that the culture solution is tap water and the number of seedlings used thirteen.

At 9:30 A. M. 3/13/15 the resistance was 272.272 ohms.
At 11:40 A. M. 3/13/15 the resistance was 271.180 ohms.
At 2:00 P. M. 3/13/15 the resistance was 269.088 ohms.
At 9:20 P. M. 3/13/15 the resistance was 270.620 ohms.
At 9:30 A. M. 3/14/15 the resistance was 269.088 ohms.
At 3:30 P. M. 3/14/15 the resistance was 269.024 ohms.

During the 30 hours in which the experiment was running there was very little change in the resistance. The concentration seemed such as would allow absorption and excretion of electrolytes at equal rates.

*Experiment VI.*

For some time it has been known that roots excrete $CO_2$. To what extent the decrease in resistance is due to the presence of $CO_2$ is not definitely known. The following experiment shows, however, that the greater part is not due to the presence of $CO_2$ as might be thought. In this case about 13% of the change in concentration is probably due to carbon dioxide alone.

Three clean Jena glass beakers were selected. These three contained equal quantities of distilled water having the same conductivity. This was accomplished by washing them successively in conductivity water until the wash water possessed the same resistance as the original water. The experiment was then started. In the first beaker no seedlings were placed. Four seedlings were put in the second beaker and the third received eight. They were put aside for 24 hours and then the conductivities were determined. The seedlings were removed and the $CO_2$ driven off by heat. As much care as possible was taken not to decrease the volume of fluid but yet be sure of driving off the carbon dioxide. Pure hot melted paraffine was poured on immediately and the beaker of water so covered was put away in the ice chest for the paraffine to harden. Pure paraffin is inert chemically and no error larger than the experimental error is believed to enter here. After a few hours the beaker was placed in the water bath to bring the solution to the proper temperature. The paraffin cap was now removed and the conductivity of the solution measured.

*Before Boiling.*

| No. seedlings | Bridge Reading | Resistance | Conductivity. |
|---|---|---|---|
| 0 | 490 | 93,690 | $1.67 \times 10^{-6}$ |
| 4 | 442 | 26,182 | $5.98 \times 10^{-6}$ |
| 8 | 538 | 17,174 | $9.12 \times 10^{-6}$ |

*After Boiling.*

| | | | |
|---|---|---|---|
| 0 | 500 | 90,000 | $1.74 \times 10^{-6}$ |
| 4 | 570 | 30,112 | $5.20 \times 10^{-6}$ |
| 8 | 503 | 19,494 | $8.03 \times 10^{-6}$ |

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The last column in the first series shows that after 24 hours the resistance of the water in which four seedlings had grown had decreased considerably over that in which no seedlings had grown. Likewise the resistance of the solution in which eight seedlings had grown is lower than that of the solution in which four seedlings had grown. It may also be observed that the decrease is not exactly proportional to the number of individuals growing in the solution. In the last column of the second series it may be noticed that the water in which no seedlings had grown had a slightly higher conductivity after boiling than before. No explanation is here offered. In the case of the other two culture solutions it is seen that boiling reduced the conductance by about 13% of what it was before boiling.

## 6. CONCLUSIONS.

In this paper the authors have endeavored to draw attention to the many biological problems, for the investigation of which the Wheatstone Bridge apparatus seems especially fitted. A plea is also made for a more general use of the principles of physical chemistry and a closer attention to the acquisition of quantitative rather than qualitative results.

Why this apparatus has not been more widely used, is in all probability due to the fact that it possesses, in its customary form a number of sources of error, which preclude accurate measurement. In addition, the taking of a measurement necessitates a considerable strain on the nerves of the operator. It is obviously very difficult to listen through a telephone for a point at which a continuous but gradually decreasing sound stops.

We have enumerated some of the errors inherent in the general method and believe that modifications, such as we have suggested make the apparatus much more precise as well as easier to operate. The induction coil was abandoned for a 60 cycle rotary converter, which gives a pure sine wave on a current of constant potential. The use of a frequency of 60 cycles per second was not attended with any appreciable error. It has been shown that in assuming polarization at 60 cycles we are assuming something neither apparent nor real. We have used this frequency for a period of two years, and have had no trouble from polarization but what could be eliminated.

The alternating current galvanometer is a better detector than the telephone for four reasons:—1. An exact balance can be made quickly and with ease. 2. Direction of deflection will indicate whether heating or polarization is taking place and the correction can be quickly made. 3. The circuit need not be closed more than an instant at a time and therefore the possible error due to heating or polarization is negligible. 4. The eye is more accurate than the ear. The customary resistance coils are replaced by Curtis Coils since these are wound for annulment of inductance and capacity. The dial decade type, a more recent form than the one used in these experiments is better because of the ease and convenience of manipulation. They also have as great a range and are better because the resistance can be increased by unit increments. At-

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tention is drawn to the necessity of using the extended coils of the bridge if a greater accuracy than .05 of 1% is desired. It is preferable to use a bridge wire of rather low resistance as it can stand wear and heavy treatment better. It will also hold its calibration more certainly. In regard to the electrolytic cells, it may be said that their construction is of utmost importance. These cells act as capacities and to balance this, a condenser must be put in across the resistance in the adjacent arm. Cells with platinized electrodes are necessary when working with a frequency of 60 cycles per second. Too much attention cannot be given to the detail of maintaining a water bath at a constant temperature. A Freas water thermostat which is accurate to .002 of a degree is efficient for this work.

A method for operating the apparatus described in this paper is suggested and a few experiments added, to show the degree of precision obtained. This apparatus has proven efficient in our hands, and a measurement can be made quickly and easily. Besides this, the results show a high degree of precision.

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The mechanical drawings, Figures 1, 2, 3, 4, 5, 6, 9 and 14 were made by P. G. Andress of the class of 1916, Michigan Agricultural College.

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TECHNICAL BULLETIN NO. 24. DECEMBER, 1915

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EXPERIMENT STATION

DIVISION OF SOILS

# THE FREEZING POINT METHOD AS A NEW MEANS OF MEASURING THE CONCENTRATION OF THE SOIL SOLUTION DIRECTLY IN THE SOIL.

BY
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EAST LANSING, MICHIGAN
1915

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## INTRODUCTION.

A definite knowledge of the concentration of the soil solution as it actually exists in the soil, under all conditions, including variation in moisture content, tillage, fertilizer treatment, season, etc., is of the greatest importance and highest interest from all standpoints—the chemical, physical, physiological, and biological. At present, the exact concentration of the natural soil solution under all the conditions enumerated above is not known, as there has been no method capable of executing a direct measurement of its magnitude.

In the present bulletin there is presented the freezing point method as a new method capable of measuring the concentration of the soil solution directly in the soil under a variety of conditions, and some of the experimental data obtained.

### REVIEW OF PREVIOUS METHODS.

A large number of methods have been used to ascertain the concentration of the natural soil solution, but nearly all of them are based upon the general principle of extracting or isolating the solution from the soil and measuring its concentration, besides other properties. The one method most extensively employed is that developed by Whitney and Cameron, (1), and consists of mixing 100 parts of soil with 500 parts of water, stirring the mixture vigorously for 3 minutes, allowing it to stand 20 minutes, and filtering the supernatant liquid through Chamberland-Pasteur filters under pressure. The results obtained by this method led Whitney and Cameron to advance the theory that the soluble mineral matter of the soils produces in general a saturated or nearly saturated solution in the soil moisture; that the magnitude of concentration of this soil solution is the same for practically all soils; and, that it is generally low, but sufficiently high for the growth and development of crops.

By employing the same method, other investigators have obtained different results and have arrived at different conclusions from those of Whitney and Cameron. One of the most extensive investigations upon the subject is that of King. (2). The results he obtained show that the amount of water-soluble material recovered in the water extract is large, and differs very widely in the various soils, and that the soils which produced the largest yields of crops or received application of fertilizers gave the largest amount of soluble material in the aqueous extracts.

More recently, Hall, (3), et al., obtained results with the Rothamsted

(1) Bul. 22, Bureau of Soils, U. S. Dept. of Agr., 1903.
(2) Bul. 26, Bureau of Soils, U. S. Dept. of Agr., 1905.
(3) Jour. Agr. Sci. 6, 1914.

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soils which agree in general with those of King. These investigators prepared artificial water extracts from certain Rothamsted experiment plots on which wheat and barley had been grown for 60 years and had received different manure treatment, by mixing 20 kgms. of dry soil with 30 kgms. of water. The results they obtained show that the concentration and composition of the soil solution are not constant but vary significantly in accordance with the composition of the soil, and its past manurial history.

This method, therefore, has apparently not only failed to give concordant results as to the concentration of the extract in the different soils, but also it tells nothing as to the exact concentration of the true solution of the soil. The addition of the water to the soil not only dilutes the natural soil solution, but also may cause a dissolving action upon the minerals, a suspension of the hydrosols, a dialysis of substances absorbed by hydrogels, etc.

Various investigators have attempted to obtain information regarding the concentration and composition of the soil solution by collecting and analyzing the drainage water of the soil. This method, however, is not only open to all the above objections, but also to the additional one that the drainage water may percolate through the spaces between the particles and may not come in complete intimate contact with the film of water around and in the soil particles, and since the processes of diffusion are slow, the drainage water may not be a true representative of the natural solution existing in the soil.

On account of the above objections to using water in isolating the natural soil solution, some investigators have tried to extract it directly from the soil by mechanical means. Two different methods have been employed to accomplish this purpose, namely, the centrifuge, and the paraffin oil. The centrifuge method has been developed and employed by Briggs, (4), and consists of whirling whetted soils in a rapidly revolving centrifuge fitted with concentric cylinders, the middle one having fine perforations, and developing a force equivalent, on the average, to 3,000 times the attraction of gravity. The soil solution is thrown out through the perforations and collects in the spaces between the perforated middle cylinder and outer cylinder. It collects usually as a perfectly clear solution, requiring no filtration. The results yielded by this method, however, have not been entirely satisfactory, owing: (1), to the small quantity of the soil solution obtainable at a time for analysis; (2), the liquid obtained is the excess or free water thrown out from the saturated soil and may not possess exactly the same concentration and composition as the film water remaining. That the concentration of the solution obtained might not be and probably could not be absolutely the same as the entire moisture of the soil, seems to be suggested by the following considerations: If the solution is not saturated or in equilibrium with the soil components, then the films which are in intimate contact with the surfaces of the soil grains would be more concentrated at any given time than the capillary or interstitial water, due to the slow rate of diffusion, and if only the interstitial water is extracted then the concentration of the extract would be less than that of the entire moisture existing in the soil. Furthermore, since the soil

(4) Buls. 22 and 31, Bureau of Soils, U. S. Dept. of Agr., 1905 and 1906 respectively.

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is a mixture of different minerals and the rate of diffusion is extremely slow, especially in the soil system, the different mineral particles would have films of different concentration, and if not all of these films are extracted or truly represented in the extract, the latter, of course, would not possess exactly the same concentration as the entire soil moisture. Again, due to the phenomenon of adsorbtion it has been suggested that that portion of the moisture immediately at the surface of the particles is more concentrated than the bulk of the solution. Whether or not this last concept is true cannot be proved; but it would seem that when a substance, be it liquid or solid, is adsorbed, becomes inoperative or inactive. (3). There is no excellent reason to believe that the solution obtained from a saturated soil will have both the same concentration and composition as the moisture of the soil short of saturation.

The paraffin oil method consists of replacing the excess of soil water with paraffin oil under pressure or suction. This method has been developed by Van Suchtelen and Itano (5), and Morgan (6), and is a modification of Ischerekov's method, (7), wherein he employed alcohol. Although a complete report of the results obtained by this method has not yet appeared, it would appear, however, from many theoretical principles as well as from some preliminary data already published (6), that this method is capable of extracting only a limited amount of the soil solution present in the soil and especially in the heavy types of soil and, consequently is open practically to the same objections as the centrifuge method.

From the foregoing brief exposition of the different methods now in vogue for studying the soil solution, it becomes very obvious that none of them is capable of furnishing definite information, either as to the actual concentration or composition of the natural soil solution as it exists in the soil under different conditions, including variation in moisture content, season, tillage, fertilizer treatment, etc. Nor does it seem possible or hopeful that they will ever be able to attain this object so long as their principle is based upon isolating the natural soil solution from the soil. From mechanical principles alone it would seem hopeless to expect to ever execute a complete separation between liquid and solid phases of the soil, or even a partial separation at the lower magnitudes of water content.

The next logical course that would suggest itself for obtaining a more definite information, either as to the actual concentration or composition of the natural soil solution, is to study the latter in the soil itself. Such study should give all the information desired and ought to be devoid of all the objections applicable to the other methods. Any method, therefore, capable of furnishing such definite information, either as to the concentration or composition, or both, of the natural soil solution under all circumstances, would be of the greatest service. From theoretical considerations, however, probably no method could ever be expected to ascertain directly the composition of the natural soil solution in the soil, but it might, the concentration.

(5) Journal f. Landw. Band 60. Seite 369-370, 1912.
(6) Michigan Board of Agriculture Reports, 1913, p. 149, and 1914 p. 210.
(7) Russian Journal f. Landw. 8, 1907, No. 2 147-66.



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A method now in vogue, which would seem at the outset of being capable of measuring the concentration of the natural soil solution in the soil, is the electrical bridge, as developed by the U. S. Bureau of Soils, (8), for the determination of soluble salts in soils. The principle of this method is dependent upon the fact that the electric current is conducted by the salt solution or its ions, and the conduction of the solution or conversely, its resistance to the passage of the current, being determined largely by its concentration.

Unfortunately, the general utility of this method in soil work is very much limited owing to the large number of factors involved in the soil medium which influence the conductivity of the electric current. It has been found, for instance, that the fine particles of the soil increase the resistance, due undoubtedly to the lengthening of the path between the electrodes by the increase in curvature of the grains. The resistance is also influenced by the thinness of the water films. These water films lose the properties of liquid in mass when they become too thin, and together with the capillary spaces in the soil, offer a greater resistance to the electric current. Furthermore, it has been found that the presence of carbonates and organic matter also materially increase the resistance of the soil solution in the soil.

From these facts, it is evident, then, that the electrical bridge cannot be used to ascertain the concentration of the soil solution with much reliance; this is not only true with soil short of saturation, but also with saturated soils. Hence, some other method is needed to measure the concentration of the soil solution in the soil.

### THE FREEZING POINT METHOD AS A NEW MEANS.

In conducting a thorough investigation on the general subject of soil temperature at this Station, the influence of soluble salts on the lowering of the freezing point of soils was also studied. It was observed that the phenomena of supercooling and freezing behave in moist soils exactly the same way as in solutions. These facts suggested at once the idea that the freezing point method might be employed to measure the concentration of the natural soil solution in the soil itself. In order to ascertain whether or not this could possibly be done, a series of preliminary experiments was instituted, using different classes of soil with various moisture contents or known concentrations of solution. The procedure consisted of placing a short column of soil in a narrow glass tube, inserting the bulb of the thermometer in this column of soil, allowing the soil mass to supercool and moving the thermometer in the soil to start solidification. It was discovered that the freezing point lowering of the soil solution in the soil, could be determined with great ease. Solidification could be started when the soil mass was supercooled to only about 0.3°C by simply moving the thermometer slightly in the soil. The lowering of the freezing point could be determined in soils from any maximum moisture content down to or below the wilting coefficient of plants. In the case of quartz sand, for instance, the lowering of the freezing point could be measured when the moisture content was only 0.7%.

(8) Buls. 8 and 16, Bur. of Soils, U. S. Dept. of Agr., 1897 and 1910 respectively.

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In every respect, therefore, the method appeared so promising from these preliminary trials of being capable of measuring the concentration of the real soil solution, that a more thorough investigation was instituted, employing a greater number of soils at different moisture contents and treating some of the soils with a large number of chemical compounds of the same concentration in order to ascertain what effect the application of soluble salts has upon the concentration of the soil solution. The results obtained are in many respects very remarkable and unexpected and promise to give us a better understanding of the fundamental principles governing the soil solution. In the following pages, therefore, there are presented a complete description of the method and the experimental data obtained.

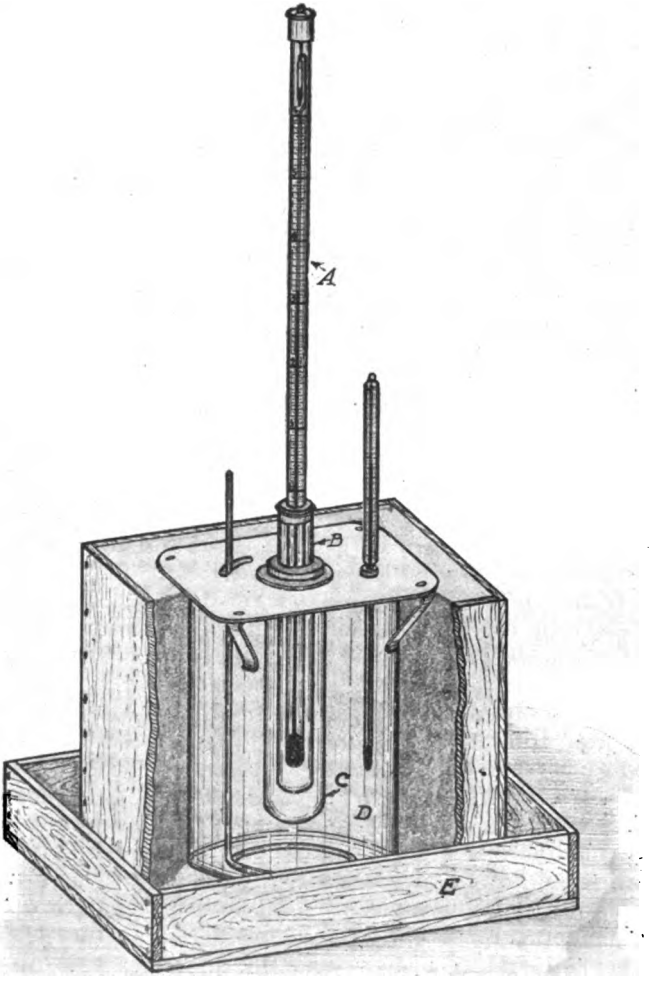


Fig. 1. Apparatus for determining the freezing point of soils.

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DESCRIPTION OF THE METHOD.

The lowering of the freezing point of soils and consequently the concentration of their solution were determined by the use of the Beckmann apparatus with certain modifications. The complete apparatus employed is shown in Figure 1. A is the Beckmann thermometer. Its whole scale is composed of only 5.860°C. Each degree is divided directly into 100 parts, and with the assistance of a pair of lenses, the readings can be made to .001°C. B is a glass tube 1 inch in diameter and 9 inches long, and contains the soil. The thermometer passes through a rubber stopper at the mouth of the tube and its bulb is inserted in the soil column until it is entirely covered. The tube B passes through a rubber stopper into the wider glass tube, C, which is 1.5 inches in diameter and 6 inches long, and acts as an air jacket to prevent rapid cooling or radiation from the soil by preventing it from coming in intimate contact with the cooling mixture contained in the battery jar, D. In order to reduce as much heat ratiation as possible from the cooling mixture and thus keep its temperature more constant, the battery jar is placed in a small wooden box and packed around with excelsior. The wooden box, having a hole at the bottom, allowed to drain into the pan, E, any water that might have fallen into it during the operation of filling the battery jar with the ice and water. F is a common thermometer which indicates the temperature of the cooling bath.

For performing a freezing point determination the following procedure was always followed. The battery jar was filled with crushed ice. To this ice was added some water and sufficient salt, usually NaCl, to produce a temperature of about —4.5°C. The Beckmann thermometer was set so that the mercury thread would come to rest towards the upper part of the scale when the bulb was held in the mixture of pure ice and distilled water, and then calibrated with distilled water. The freezing point of distilled water was taken as zero, and the lowering of the freezing of soils was obtained by getting the difference between the freezing point reading of the distilled water and that of the soil. The freezing point reading of the soil was determined by placing about one inch column of soil in the glass tube, and then inserting the bulb of the thermometer into this column of soil until it was completely covered. The tube containing the soil and the thermometer was placed into the air jacket and allowed to cool in the cooling bath. The temperature of the soil was allowed to fall until it was about 1°C lower than the freezing point of the soil, i. e., supercooled. In order to start solidification, the soil tube was held firmly with the left hand near its mouth, and with the right hand, the thermometer was moved or rotated toward and away from the operator, until the temperature began to rise. The temperature was allowed to rise until it came to rest at a certain point on the scale and remained at that point for some length of time. This maximum temperature attained was considered as the proper freezing point of the soil and recorded. The thermometer was always tapped before taking the final reading.

It was discovered very soon at the beginning that it required a very long time for the soil to cool in the air jacket, owing to the poor heat

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conductivity of the air in the jacket. It was finally decided to hasten the process by bringing the tube containing the soil and the thermometer in intimate contact with the cooling mixture and allowing the soil mass to cool to about 5°C above the freezing point of water, or until there was only a small amount of mercury at the upper part of the reservoir, and then taking out the soil tube from the cooling mixture and inserting it at once into the air jacket and letting the soil mass to cool slowly. This procedure, however, was generally successful when the soils contained a high moisture content, but not when they had a low water content. In the latter case solidification would commence before supercooling had taken place and the proper lowering of the freezing point could not, of course, be determined. The plan, therefore, was modified, and in its final form consisted of cooling the soil directly in the cooling mixture until all the mercury had left the reservoir and then taking that portion of the tube containing the soil between the palm of the hand and warming it until the mercury thread began to rise again. The tube was then placed into the air jacket in the cooling bath and allowed the soil to cool gradually. The process of warming the soil slightly after it was taken from the cooling mixture proved a great success as it almost always prevented the occurence of solidification before supercooling had taken place. With the above plan in its final form, therefore, the time required for making a freezing point determination was reduced about 60%, and as many as 30 freezing point determinations have been made in one day—8 hours.

For taking off the initial excess of heat from the soil system it was found convenient to employ a second battery jar containing a cooling mixture of the same temperature as the first.

It was found very essential to allow the soil to supercool to about 1°C below its freezing point, although solidification could be induced at the supercooling of only about 0.3°C, in order to obtain quicker and more accurate readings. By supercooling the soil to about 1°C, sufficient solid or crystal ice of the pure soil water is immediately separated to warm the soil system quickly up to its proper freezing point. If the amount of the supercooling is small, the separation of the solvent is very slow, the thermometer comes to rest only very slowly, and the readings obtained are not accurate, especially with soils of low moisture content.

On the other hand, too much supercooling is also a source of error, and especially if the soil solution is highly concentrated. The freezing point of a solution is the temperature at which ice and solution exist in equilibrium. Upon freezing, pure water separates in the solid phase, and the liquid which remains, and whose temperature in equilibrium with the mass of the ice crystals, is read from the thermometer, is not the same, but more concentrated than the original solution. In consequence, the observed depression of the freezing point is lower than the true lowering of the freezing point of the solution under investigation. The amount of solid solvent formed depends upon the amount of supercooling and the heat of solidification of the solvent, which is obviously equal to its heat of fusion. The greater the undercooling, therefore, and the larger the amount of ice that will separate at the

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moment of freezing, the greater will be the concentration of the remaining solution, and, consequently, the larger will be the error on the lowering of the freezing point. In order to compensate for this source of error as much as possible, a correction may be introduced. Let u be the undercooling of the solution in degrees, s, the specific heat of the liquid, and l, the latent heat of fusion of unit weight of the solvent; then, $\frac{su}{l} = f$, where f is the amount by which the solution will be concentrated, due to the separation of ice.

While this formula may be applicable in case of solutions in mass, it was not considered to be so in soils, and consequently it was not employed in the final determination of the lowering of the freezing point of soils. The error arising from this source, however, is not great enough to affect the results very appreciably considering the amount of undercooling employed.

The length of time at which the mercury column remained at the proper freezing point seems to be inversely proportional to the concentration of the soil solution. This phenomenon is, of course, due to the separation of the solid solvent which causes the solution to become more concentrated and lowers its freezing point. When the soil solution is very dilute, the relative mass of pure water is large, and the time required for all of it to freeze in the solid phase so that the freezing point may sink, is very long. Hence, the real freezing point remains at its place a long time. When the soil solution is concentrated. however, the relative mass of the pure solvent is not large, and a small quantity of ice separated, concentrates the mass of the solution and lowers the freezing point, hence, the length of period during which the actual freezing point remains at its place, is short. The time varies from several minutes, in the soil with high moisture content, to less than a minute in the soil with a very low water content.

It has already been stated that the temperature of the cooling bath was maintained at about —4.5°C. It was found that if the temperature was lower than this the rate of cooling of the soil mass would be too rapid and solidification would commence before supercooling had occurred. The temperature then would descend very slowly and the proper lowering of the freezing point could not be determined accurately. On the other hand, if the temperature was less than —4.5° the soil mass would cool very slowly, and consequently, would take much longer to make a freezing point determination.

From theoretical reasons, a too low temperature in the cooling bath involves an error in the final reading owing to the radiation and conduction of heat from the soil. The greater the difference in temperature between that of the soil system and the cooling bath the greater is the amount of radiation from the soil and consequently the lowering of the freezing point will be slightly greater. The amount of error arising from this source, however, is also very small.

As previously mentioned, the lowering of the freezing point of soils could be measured from any maximum water content down to a very

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low water content, probably lower than at the wilting coefficient of plants. Below this last lower limit, solidification could not be induced very readily. At the high moisture content duplicate determinations of the same sample would agree exactly with one another, or vary only a few thousandths of a degree. At the low moisture content, however, the duplicate determinations of the same sample would agree only with some soils, such as the quartz sand and sandy soils, but with other soils, such as the clay and loam, the variation would be considerable, but always consistent, namely, the first lowering of the freezing point was always greater than the second. The duplicate determination of different samples of the same soil, however, would agree very closely, even with the latter soils. The probable reason for the change or decrease in the lowering of the freezing point with successive freezings in the case of colloidal soils at low moisture content will be offered subsequently.

Great care was always exercised to secure as uniform moisture content throughout the entire sample of soil under investigation, as possible. It was recognized that if some particles of the soil sample were not moistened the lowering of the freezing point would be less, because not all of the soluble material would be in solution. The soil sample short of saturation, therefore, was prepared by passing it through a sieve several times and mixing it thoroughly with the fingers. Even then, it cannot be said that all of the soil grains were moistened exactly to the same extent, but if they were all sufficiently moist so that their film would freeze upon supercooling then the freezing point depression observed would be an average of the lowering of the freezing of the various particles. The soil samples which contained high moisture contents and could not be passed through the sieve, especially if they consisted of the colloidal types, were thoroughly worked with the fingers. Great precaution was taken, of course, to have the latter thoroughly clean. There is some danger of salts being added to the soil through perspiration of the fingers, but the amount would be so insignificant that it could never be detected by the method.

It was feared at the outset that on account of the compressability of the mercury bulb great errors might be caused by the expansion of the soil upon freezing. A thorough examination of this point, however, proved that an error might arise from this source only when the soil in the tube was extremely compacted, but otherwise there is none. To guard against any possibility of error of this nature, however, the soil in the tube was only slightly compacted and the bulb of the thermometer was always moved in the soil at the beginning so that it would be loose.

In calibrating the thermometer with distilled water and attempting to keep it at that set point for several days, it was found that it would not remain the same, but would change. This change was not always in the same direction, but varied in both directions. In examining several treatises on thermometry, no mention was made of this fact, and could not be accounted for at the beginning of the investigation. It was soon discovered, however, that it was caused by the difference in temperature of the room in which the thermometer was calibrated

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at the different days. Thus if the room temperature was 20° on one day and 25° on another day the freezing point of the same distilled water would be different and indeed the reading on the thermometer would be greater at the highest temperature. When the room temperature, however, remained unchanged, exactly the same freezing point of the distilled water would be obtained every day for a long time. Evidently the room temperature influences the exposed mercury column. This effect, however, is not the same as that due to the emergent column. The magnitude of the change depends upon the difference in the temperature. Preliminary experiments showed that a temperature difference of $\pm$ 10°C caused a change of $\pm$ .020°C on the freezing point of water. If it is desired to save time by not calibrating the thermometer too often a correction such as the above could be worked out and applied to the readings obtained. In the present investigation, however, the room temperature remained quite constant and it was not necessary to apply a correction.

## EXPERIMENTAL DATA.

### The Lowering of the Freezing Point of Soils at Different Moisture Contents; and under Other Conditions.

In accordance with the foregoing method and the necessary precautions mentioned, the lowering of the freezing point of a large number of soils was determined. In the present paper, however, only the results of typical representatives of diverse classes of soil are presented with the view of showing mainly the character of results that this method yields. All the soils employed, with the exception of quartz sand and kalolin, were taken from the field and were consequently in the natural state. Since preliminary trials showed that the lowering of the freezing point varied with the moisture content, it was decided to measure the former in each soil at two different moisture contents, low and high. These two different degrees of water content were arbitrarily chosen for purposes of comparison, and are not exactly equivalent for the various types of soil. The low moisture content does not indicate the lowest limit at which solidification would occur, for in many of the soils the water content could well have been reduced considerably more, but at this low degree of water content the solidification could be induced very readily and the readings could be absolutely depended upon. The high moisture content may be taken to represent the point of saturation. In order to secure these two extreme and opposite degrees of water content, water was either added to the soil, if it was not already saturated when taken from the field, or withdrawn from it by spreading it in a thin layer and allowing it to lose water until the desired moisture content was reached. In many cases the soil as taken from the field was sufficiently dry to be used immediately for the freezing point determination. The majority of the soils presented in Table 1 were collected in the vicinity of this College, a few were sent in from other counties of the State, and they all constitute the upper 6-inch layer of the field.

In order to obtain an idea as to the magnitude of concentration and

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osmotic pressure that the depressions of the freezing point represent at the opposite extreme moisture contents, the values of both of these factors have been calculated and are presented together with their respective depressions of the freezing point. The concentration is expressed in parts per million of solution and was calculated directly from soil water extracts and not from any particular pure chemical compound or combinations therefrom. The procedure for accomplishing this consisted of mixing a large amount of soil with a small quantity of water, allowing the mixture to stand for about two days with occasional stirring, and then filtering the solution through a filter paper. A portion of this solution was used to measure its lowering of the freezing point and the remainder was employed to determine its total solid matter by evaporating a definite volume of it to dryness and weighing the residue. From the freezing point depression of the extract and its corresponding amount of solid material present, the concentration in p. p. m. of solution that might be represented by the values of the lowering of the freezing point of each soil was calculated. There were three different types of soil from which water extracts were made; namely, clay, loam and peat. It was found by calculation that 100 p. p. m. of solid material in the soil water extract gave the following values of the lowering of the freezing point; clay, .0038°, loam .0030°, and peat .0031°C. Evidently equal concentration of the water extracts of these three different types of soil caused about the same lowering of the freezing point. This is extremely interesting in view of the fact that on account of the marked difference in the physical and chemical composition of these soil types entirely different results might have been expected. On account of this remarkable closeness of the lowering of the freezing point for all three soil extracts, an average was taken in the computation of the concentration of the soil solution of the various soils as represented by their lowering of the freezing point.

It is readily realized that the foregoing procedure of estimating the magnitude of concentration that the various values of the freezing point depression might represent is open to many objections, but it is believed that it is perhaps the best way of obtaining an idea as to the magnitude of this value.

The osmotic pressure was calculated from a table of osmotic pressures as worked out by Harris and Gortner, (9), from the formula $\pi = 12.06\Delta - 0.021\Delta^2$, where $\pi$ is the osmotic pressure in atmospheres, and $\Delta$ is the lowering of the freezing point in centigrade degrees. For convenience and usefulness this table is reproduced herewith.

(9) Am. Jour. Bot. 1, 75-78, 1914.

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*Table 1. Osmotic Pressure in Atmospheres for Depression of the Freezing Point to 2.996° C.*

| Δ | Hundredths of Degrees, Centigrade. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 0.0 | 0.000 | 0.121 | 0.241 | 0.362 | 0.482 | 0.603 | 0.724 | 0.844 | 0.965 | 1.085 |
| 0.1 | 1.206 | 1.327 | 1.447 | 1.458 | 1.688 | 1.809 | 1.930 | 2.050 | 2.171 | 2.291 |
| 0.2 | 2.412 | 2.532 | 2.652 | 2.772 | 2.893 | 3.014 | 3.134 | 3.255 | 3.375 | 3.496 |
| 0.3 | 3.616 | 3.737 | 3.857 | 3.978 | 4.098 | 4.219 | 4.339 | 4.459 | 4.580 | 4.700 |
| 0.4 | 4.821 | 4.941 | 5.062 | 5.182 | 5.302 | 5.423 | 5.543 | 5.664 | 5.784 | 5.904 |
| 0.5 | 6.025 | 6.145 | 6.266 | 6.386 | 6.506 | 6.628 | 6.747 | 6.867 | 6.988 | 7.108 |
| 0.6 | 7.229 | 7.349 | 7.469 | 7.590 | 7.710 | 7.830 | 7.951 | 8.071 | 8.191 | 8.312 |
| 0.7 | 8.432 | 8.552 | 8.672 | 8.793 | 8.913 | 9.033 | 9.154 | 9.274 | 9.394 | 9.514 |
| 0.8 | 9.635 | 9.755 | 9.875 | 9.995 | 10.12 | 10.24 | 10.36 | 10.48 | 10.60 | 10.72 |
| 0.9 | 10.84 | 10.96 | 11.08 | 11.20 | 11.32 | 11.44 | 11.56 | 11.68 | 11.80 | 11.92 |
| 1.0 | 12.04 | 12.16 | 12.28 | 12.40 | 12.52 | 12.64 | 12.76 | 12.88 | 13.00 | 13.12 |
| 1.1 | 13.24 | 13.36 | 13.48 | 13.60 | 13.72 | 13.84 | 13.96 | 14.08 | 14.20 | 14.32 |
| 1.2 | 14.44 | 14.56 | 14.68 | 14.80 | 14.92 | 15.04 | 15.16 | 15.28 | 15.40 | 15.52 |
| 1.3 | 15.64 | 15.76 | 15.88 | 16.00 | 16.12 | 16.24 | 16.36 | 16.48 | 16.60 | 16.72 |
| 1.4 | 16.84 | 16.96 | 17.08 | 17.20 | 17.32 | 17.44 | 17.56 | 17.68 | 17.80 | 17.92 |
| 1.5 | 18.04 | 18.16 | 18.28 | 18.40 | 18.52 | 18.64 | 18.76 | 18.88 | 19.00 | 19.12 |
| 1.6 | 19.24 | 19.36 | 19.48 | 19.60 | 19.72 | 19.84 | 19.96 | 20.08 | 20.20 | 20.32 |
| 1.7 | 20.44 | 20.56 | 20.68 | 20.80 | 20.92 | 21.04 | 21.16 | 21.28 | 21.40 | 21.52 |
| 1.8 | 21.64 | 21.76 | 21.88 | 22.00 | 22.12 | 22.24 | 22.36 | 22.48 | 22.60 | 22.72 |
| 1.9 | 22.84 | 22.96 | 23.08 | 23.20 | 23.82 | 23.44 | 23.56 | 23.68 | 23.80 | 23.92 |
| 2.0 | 24.04 | 24.16 | 24.28 | 24.40 | 24.52 | 24.63 | 24.75 | 24.87 | 24.99 | 25.11 |
| 2.1 | 25.23 | 25.35 | 25.47 | 25.59 | 25.71 | 25.83 | 25.95 | 26.07 | 26.19 | 26.31 |
| 2.2 | 26.43 | 26.55 | 26.67 | 26.79 | 26.91 | 27.03 | 27.15 | 27.27 | 27.39 | 27.51 |
| 2.3 | 27.63 | 27.75 | 25.87 | 27.99 | 28.11 | 28.23 | 28.34 | 28.46 | 28.58 | 28.70 |
| 2.4 | 28.82 | 28.94 | 29.06 | 29.18 | 29.30 | 29.42 | 29.54 | 29.66 | 29.78 | 29.90 |
| 2.5 | 30.02 | 30.14 | 30.26 | 30.38 | 30.50 | 30.62 | 30.74 | 30.86 | 30.98 | 31.09 |
| 2.6 | 31.21 | 31.33 | 31.45 | 31.57 | 31.69 | 31.81 | 31.93 | 32.05 | 32.17 | 32.29 |
| 2.7 | 32.41 | 32.53 | 32.65 | 32.77 | 32.89 | 33.00 | 33.13 | 33.25 | 33.36 | 33.48 |
| 2.8 | 33.60 | 33.72 | 33.84 | 33.96 | 34.08 | 34.20 | 34.31 | 34.43 | 34.56 | 34.68 |
| 2.9 | 34.79 | 34.91 | 35.04 | 35.16 | 35.27 | 35.39 | 35.51 | 35.63 | 35.75 | 35.87 |

The osmotic pressures corresponding to depressions of hundredths of degrees may be read directly from the table. Furthermore, for all practical purposes the first differences x 0.1 may be taken as 0.012, hence, pressures when Δ is read to thousandths of a degree may be at once determined. Thus. suppose Δ to be 1.224°. For Δ = 1.24° pressure = 14.92°. 14.92 (4 x 0.012) = 14.968.

The lowering of the freezing point of various types of soils, then, at two different moisture contents, together with the calculated concentration in p. p. m. of solution and osmotic pressure in atmospheres that these values of the freezing point depression might represent, are shown in Table 2.

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*Table 2. Lowerings of the Freezing Point and their Corresponding Concentration and Osmotic Pressure of Various Types of Soil.*

| Name of Soil. | Quarts sand. | | Sand. | | Sand. | | Sand. | | Sandy loam. | | Sandy loam. | | Sandy loam. | | Sandy loam. | | Loam. | | Loam. | | Loam. | | Loam. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage of Moisture.... | 1.50 | 15.0 | 2.60 | 21.98 | 4.44 | 23.80 | 6.03 | 23.00 | 4.79 | 19.30 | 10.33 | 24.50 | 8.35 | 23.09 | 8.30 | 21.53 | 16.39 | 35.84 | 11.18 | 20.97 | 16.77 | 31.41 | 18.83 | 33.18 |
| Freezing point Depression. . | .070 | .007 | .130 | .010 | .060 | .010 | .100 | .010 | .210 | .015 | .137 | .012 | .470 | .025 | .450 | .020 | .830 | .022 | .455 | .028 | .810 | .025 | .420 | .025 |
| Parts per Million..... | 2,121 | 212 | 3,939 | 303 | 1,818 | 303 | 3,030 | 303 | 6,364 | 455 | 4,152 | 364 | 14,244 | 758 | 13,636 | 606 | 25,154 | 667 | 13,780 | 848 | 24,546 | 758 | 12,728 | 758 |
| Osmotic Pressure..... | .844 | .084 | 1.568 | .121 | .724 | .121 | 1.206 | .121 | 2.532 | .181 | 1.652 | .145 | 5.664 | .301 | 5.302 | .241 | 9.995 | .265 | 5.483 | .337 | 9.755 | .301 | 5.062 | .301 |

| Name of Soil. | Silt loam. | | Silt loam. | | Clay. | | Clay. | | Clay. | | Clay. | | Clay loam. | | Clyde loam. | | Clay loam. | | Kaolin. | | Peat. | | Peat. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Percentage of Moisture.... | 17.40 | 34.76 | 13.09 | 30.00 | 18.80 | 36.50 | 22.91 | 59.02 | 23.10 | 63.43 | 15.42 | 30.50 | 18.52 | 30.32 | 22.91 | 39.85 | 26.28 | 49.13 | 13.50 | 78.60 | 138.97 | 186.94 | 122.1 | 360.2 |
| Freezing Point Depression... | .665 | .035 | .352 | .022 | .955 | .034 | .825 | .020 | .845 | .010 | .462 | .020 | .755 | .025 | .825 | .050 | .365 | .015 | 1.025 | .025 | .050 | .003 | .062 | .002 |
| Parts per Million..... | 20,153 | 1,061 | 10,667 | 667 | 28,940 | 1,030 | 25,033 | 606 | 25,606 | 303 | 14,000 | 606 | 22,880 | 758 | 25,003 | 1,515 | 11,060 | 455 | 31,060 | 758 | 1,515 | 91 | 1,879 | 61 |
| Osmotic Pressure..... | 8.011 | .422 | 4.243 | .265 | 12.04 | .410 | 9.935 | .241 | 10.72 | .121 | 5.567 | .241 | 9.093 | .301 | 9.935 | .603 | 4.3 99 | .181 | 12.340 | .301 | .603 | .036 | .748 | .024 |

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From a careful examination and consideration of the above results it will at once be recognized that they are extremely unusual and indeed almost incredible, in view of the present ideas concerning the soil solution. They show, for example, that at the high moisture content, the lowering of the freezing point and consequently the concentration, are very small and only slightly different for the various classes of soil, but at the low moisture content, the lowering of the freezing point and consequently also the concentration, are extraordinarily high and very different for the same classes of soil as above. Thus, at the high water content, the magnitude of the lowering of the freezing point varies from .003°C in case of the peat, to 0.050°C in humus loam, but the mean for the majority of the soils is around 0.010° and 0.020°C. At the low moisture content, however, the magnitude of the depression varies from 0.070°C in the case of washed quartz sand of medium texture, to 0.955°C in medium heavy clay, and tends to increase from soils composed mainly of pure silica, to soils containing complex aluminum-silicates and organic matter.

These values of the freezing point depression at the low moisture content would have been still greater had the moisture content been farther lowered. It is to be noted, however, that with some soils, the lowering of the freezing point could not be much more increased with further reduction in water content because they have approached the point of dryness. Thus, the quartz sand and one of the sandy soils contain only 1.5 and 2.6% of water, respectively. While many of the clays and clay loams contain as much as 20% and one of the peats, 138.97% moisture. Yet, when the quartz sand and sandy soils have reached the point of dryness, their maximum lowering of the freezing point is only about 0.100°C, while that of the clays and clay loams, whose moisture content is more than enough to saturate these sandy soils, give a lowering of the freezing point close to 1.000°C, or ten times greater.

The concentration that the lowering of the freezing point at the low moisture content of the more complex soils represents, is really tremendous. Thus, the depression of .935°C in one of the clay soils represents a concentration, as calculated by the method already described, of 28,940 p. p. m. and an osmotic pressure of 12.04 atmospheres. These great magnitudes of concentration and osmotic pressure of clay are typical examples of all the complex types of soils investigated. In the simple types of soils, however, as typified by quartz sand, the corresponding depression of .070°C indicates a concentration of only 2121 p. p. m. and an osmotic pressure of 0.800 atmospheres.

On the other hand, the concentration that the depression of the freezing point of all the soils represents at the high moisture content, is comparatively low, averaging about 600 p. p. m. for the majority of the complex soils and about 300 p. p. m. for the simple soils, with an osmotic pressure of .350 and .150 atmospheres, respectively.

A further examination of Table 2 also reveals the remarkable fact that the lowering of the freezing point increases in all the soils, with the exception of quartz sand, at a far greater rate than the percentage of water decreases. In other words, the ratio of the lowering of the

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freezing point and of the water content are not inversely proportional, (approximately), to each other as might be expected, except only in quartz sand. Thus, clay at 36.5% of moisture gave a depression of .034°C, and at 18.80%, .955°C, the ratio of the percentage of water at the two moisture contents is only 1.94, while that of the depression of the freezing point is 27.11. A sandy loam, which at 21.53% of water gave a depression of .020°C, and at 8.30%, .450°C, shows a ratio of 2.35 in percentage of water to 22.5 in the lowering of the freezing point. In the case of quartz sand, however, the ratio of the depression is directly inversely proportional to the water content. Thus, at 1.5% of water content the depression is .070°C and at 15% it is .007°C, the inverse ratio, therefore, being 10 to 10, respectively.

Apparently, the quartz sand yields different results from all the other types of soil and its data can be mathematically expressed by the simple equation M.D. = K. where K is a resultant constant, M is the percentage of moisture content and D, the observed depression of the freezing point. The following table serves to show how close the data of the quartz sand follow the above formula:

*Table 3. Lowering of the Freezing Point of Quartz Sand at Various Moisture Contents.*

| Percentage of moisture. | Observed lowering of the freezing point. | Constant K. |
|---|---|---|
| 1.5 | .070 | .105 |
| 3.7 | .026 | .0962 |
| 7.5 | .012 | .0920 |
| 15.0 | .007 | .105 |

The last column to the right contains the value or constant obtained by multiplying the percentage of moisture by the observed lowering of the freezing point. It will be noted that the constant K is practically the same at all moisture contents, which goes to prove that the data of the quartz sand follow the foregoing mathematical formula remarkably close.

The same constant is obtained even when the quartz sand is treated with a salt solution and allowed to dry and then determining its depression at different moisture contents.

The question now rises, do the results of the other types of soil also follow some mathematical law, i. e., are they expressable mathematically? In order to obtain definite data upon this point the lowering of the freezing point of a large number of soils was determined at various moisture contents. The procedure consisted of allowing the soils to become air dry and then adding different quantities of water to the same amount of soil, allowing the mixture to stand in a moist atmosphere at room temperature for about 24 hours and then determining its lowering of the freezing point. The moisture content varied from very low to very high. Great precaution was taken to moisten the whole mass of each sample very uniformly. Several types of soil were used for

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this study, but in Table 4 the results of only a sandy loam, humus loam, silt loam, and clay are presented, which suffice to illustrate the general principle. These results are graphically illustrated by Figure 2.

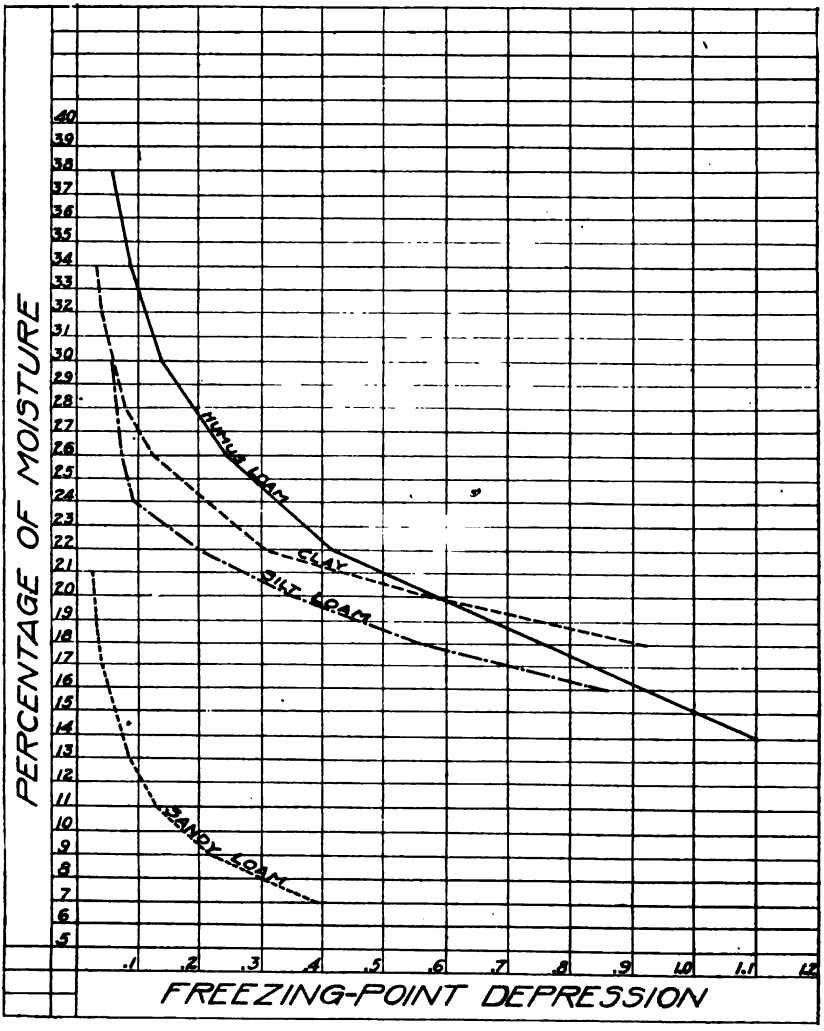


Fig. 2. Curves showing the increase in the lowering of the freezing point of soil with the decrease in moisture content.

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*Table 4. Lowering of the Freezing Point of Various Types of Soil at Different Moisture Contents.*

| Clay. | | | Silt Loam. | | |
|---|---|---|---|---|---|
| Percentage of moisture. | Observed lowering of the freezing point. | Calculated lowering of the freezing point. | Percentage of moisture. | Observed lowering of the freezing point. | Calculated lowering of the freezing point. |
| 18 | .922 | | 16 | .860 | |
| 20 | .580 | .6242 | 18 | .560 | .6880 |
| 22 | .307 | .3916 | 20 | .350 | .4480 |
| 24 | .212 | .2078 | 22 | .200 | .2800 |
| 26 | .127 | .1435 | 24 | .095 | .1600 |
| 28 | .082 | .0859 | 26 | .076 | .0760 |
| 30 | .062 | .0555 | 28 | .071 | .0608 |
| 32 | .042 | .0419 | 30 | .060 | .0568 |
| 34 | .034 | .284 | ..... | ..... | ..... |
| **Humus Loam.** | | | **Sandy Loam.** | | |
| 14 | 1.200 | ..... | 7.0 | .390 | ..... |
| 18 | .760 | .7888 | 9.0 | .220 | .2925 |
| 22 | .420 | .4995 | 11.0 | .130 | .1650 |
| 26 | .245 | .2761 | 13.0 | .087 | .0975 |
| 30 | .140 | .1610 | 15.0 | .065 | .0642 |
| 34 | .089 | .0920 | 17.0 | .040 | .0487 |
| 38 | .0585 | .0585 | 19.0 | .030 | .0300 |
| ..... | ..... | ..... | 21.0 | .025 | .0225 |

The lowering of the freezing point at the different moisture contents is shown in the second column of each soil. These results also follow a mathematical law and indeed the geometric progression law, i. e., the lowering of the freezing increases in a geometric progression, while the percentage of water decreases in an arithmetic progression. The agreement between the observed and calculated values of the lowering of the freezing point is remarkably close,—considering the nature of the soil medium—as shown by the last two columns of each soil. The calculated values were obtained by dividing one of the observed depressions by the one preceding and multiplying the various lowerings of the freezing point by the ratio thus obtained. Since the depressions at the higher moisture content are considered to be the most accurate they were used for obtaining the ratio or constant. Probably it would have been permissible to take an average of all the ratios between the different values of the depression and in which case the calculated values would be much closer to the observed values. If the results then follow the geometric progression law they are expressable by the equation $D = AR^{n-1}$, where D is the depression of the freezing point, A the first depression, R the ratio of any depression (except the first) to the preceding one, and n the number of the depression. According to this formula if the lowering of the freezing of a soil is determined at two different moisture contents it can be calculated at any other moisture content.

The main facts brought out by the investigation thus far may be summarized then, as follows: At low moisture content the lowering of the freezing is extraordinarily high and very different for the various types of soil, being lowest in the sandy types and highest in the clay

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types; at high moisture content, however, the lowering of the freezing point is relatively very low and only slightly different for the diverse classes of soil; in all the different soils with the exception of quartz sand, the depression of the freezing point increases in a geometric progression as the percentage of moisture decreases in an arithmetic progression; in the case of quartz, however, the lowering of the freezing point increases directly as the moisture content decreases; the magnitude of concentration and osmotic pressure that the lowerings of the freezing point represent at the low moisture content, are tremendously high, especially in the complex types of soil, but at the high moisture content, they are comparatively very small.

It will at once be admitted, therefore, that these results are extremely unusual and do not harmonize with the present views concerning the soil solution. It is almost universally believed, for instance, that the soil solution is very dilute, and according to a theory advanced by Whitney and Cameron, (10), many years ago, the soil solution is not only very dilute, but also, its magnitude of concentration tends to remain constant and to be the same for practically all soils, since it tends to be saturated or in equilibrium with the mineral constituents of the soil. They based their theory upon the assumption that the mineral substances comprising the soil are complex salts with slight solubilities in water, and consequently, only small amounts of them would be required to go into solution to form a saturated solution. Since the solution is saturated in respect to the mineral constituents of the soil, the addition of a soluble salt, such as KCl, may not increase the concentration but would force back the disociation of the corresponding ions and thus maintain a constant concentration of solution.

Since the discovery of the phenomena of absorption and adsorption of salts by soils it has been suggested, especially by Schloesing, and at present very widely believed, that these properties control or regulate the concentration of salts in solution and that the concentration of the solution of any given soil tends to remain practically constant. This view is well expressed in a recent paper by Bogue, (11). To quote: "But, the concentration of the salts in the soil solution tends to remain practically constant for any given soil. Thus, for example, if the concentration of potassium in the soil moisture should be lessened by the leaching of heavy rains, or the taking up of potassium by the plants, or by any other cause, this concentration would quickly be re-established by the soil giving up of its absorbed potassium until the constant was again reached. Or, if on the other hand, the concentration of potassium in the soil solution should be increased as by the application of a soluble fertilizer, or by evaporation of the soil moisture, the constant would be restored by the absorption of the excess potassium by the soil."

The foregoing results on the lowering of the freezing point, as well as other data subsequently to be presented, diametrically oppose the above theories. Contrary to both these theories, the concentration of the soil solution as indicated by the lowering of the freezing point, does

(10) Bul. 22, Bureau of Soils, U. S. Dept. of Agr., 1903.
(11) Jour. Phys. Chem., 19, 665, 1915.

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not remain constant but varies tremendously, and indeed increases greatly with the decrease in moisture content, so that at a low water content the magnitude of the concentration is very great. Furthermore, the magnitude of concentration at a low moisture content is not only not the same for the various types of soil, but it is far greater in those classes which would be expected to possess the greatest absorbtive power.

Hence, if either one or both of the above theories are correct, then the foregoing results on the lowering of the freezing point do not represent actual concentration of solution, but they are influenced by some physical force. One of the physical factors which might produce such results, it was thought, is the pressure with which the water films are held by the soil grains. It is well known, for example, that pressure lowers the freezing point of water to the extent as shown by the data in Table 5.

*Table 5. Effect of Pressure on the Freezing Point of Water.*

| Pressure in Atmospheres. | Freezing Point of Water Lowered. |
|---|---|
| 138.888 | 1.0°C |
| 277.777 | 2.0 |
| 416.666 | 3.0 |
| 555.550 | 4.0 |
| 694.440 | 5.0 |
| 13,000.000 | 18-20 |

It was reasoned that at the low moisture content the pressure of the water films would be greater than at the high moisture content and consequently the lowering of the freezing point would be greater in the former than in the latter.

A critical theoretical examination of this hypothesis, however, has failed to show that the pressure is the probable cause of the results noted. Furthermore, all direct and indirect evidences point overwhelmingly against it. Some of the evidences against it may be mentioned the following: (1). The rate of increase of the lowering of the freezing point with the decease in moisture content, is practically the same from the lowest to the highest moisture content. (2). The washed quartz sand which would not be expected to contain a solution of high concentration gives a depression of only .070°C at 1.5% moisture content or almost at the point of dryness, while clay, which would be expected to possess a very highly concentrated solution, gives a lowering of the freezing point of .955°C at 18.80% moisture. The clay, at a high moisture content where the pressure of the water films would be reduced to minimum, gives a freezing-point depression many times greater than that of the quartz sand at the point of dryness. (3). The water which is adsorbed or condensed on the surfaces of the soil particles on account of the great pressure probably resulting from the adhesive forces, is conceived to be removed from the liquid phase and becomes solid like water of crystallization and probably takes no part in the freezing, as will subsequently be discussed.



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There appears to be no other physical factor known to affect the freezing point of water. A number of minor possibilities have been suggested, but after a careful examination and consideration they all have been discarded.

The conclusion seems to be inevitable, therefore, that the great lowerings of the freezing point noted are caused by and represent actual concentration of solution and therefore contradict the foregoing theories regarding the constancy and magnitude of concentration of the soil solution.

No definite and proved theory can be offered to explain this apparent great increase in concentration of the soil solution with decrease in moisture content. The following hypothesis, however, would appear to explain the phenomena and is here tentatively offered.

It is assumed that the soil solution contains salts or their ions, produced by the reaction of the dissolved components of the soil minerals, hydrolysis of the minerals, application of fertilizers, decomposition of organic matter, etc. These salts have as a rule a high solubility and would require a large amount of them to form a saturated solution. They are formed rather slowly and since the frequent rains, especially in the humid regions, tend to leach them away only a relatively small amount of them is present at a time. At a high moisture content these salts are diluted and the lowering of the freezing is small. As the moisture content, however, is reduced they are concentrated and the lowering of the freezing point becomes greater. Since these salts are present only in relatively small amounts, they do not form a saturated solution, or at least many of them do not.

A critical consideration of the character of the soil system and a thorough examination of the available general data of the soil solution, as obtained through soil water extracts, drainage water, etc., lend considerable support to the above hypothesis.

A consideration of the soil mass shows that it is a heterogeneous mixture composed of solids, gases, and a liquid, and inhabited by living organisms. The solid portion, in normal soils, is composed of mineral debris and organic matter, from rock and from plant and animal degradation and decomposition, respectively. Both of these classes of solid matter are guadually reduced to the liquid state. The organic matter, for instance, mainly through the activities of the living organisms, is rendered soluble and many organic and inorganic compounds are formed, including the nitrates, humic acids, etc. The nitrates may exist as $NaNO_3$, $Ca(NO_3)_2$, $Mg(NO_3)_2$, etc., depending upon the preponderance of the base present to unite with the acid. These salts have a very high solubility constant and to form a saturated solution a very great amount of them is required. Thus, to form a saturated solution at 20°C would require 83.7 grams of $NaNO_3$, 31.6 gm. of $Mg(NO_3)_2$, and 54.8 gm. of $Ca(NO_3)_2$, in 100 gm. of water. It is very doubtful, therefore, whether a normal soil and especially under humid conditions ever possesses a saturated solution in respect to these salts. Assuming, therefore, that there is a certain amount of nitrate salts in the soil solution then it naturally follows that at a high moisture content it is

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diluted, and, as the percentge of water is reduced, it becomes more concentrated; hence, the lowering of the freezing point would tend to increase from the high to the low water content.

The dissolution of the mineral matter is accomplished by the solvent action of water aided by the foreign substances that it might be charged with, such as acids, bases, and salts. The soil minerals, however, are as a rule but slightly soluble and their rate of solution is generally very slow, so slow indeed that it requires months and even years, at least with certain minerals, to form a saturated solution. Thus, Cameron and Bell, (12), found that by placing powdered glass, orthoclase, albite, and some Podunk fine sandy loam with water in paraffin cylinders and rotating them in a constant temperature bath at 27°C for about 9 weeks, equilibrium was not yet attained. Many if not all of the common soil forming materials, however, undergo hydrolysis and thereby increase their degree and rate of solubility. Their solubility may be further increased by the addition of soluble compounds yielding non-common ions, or by the reacting with some of the minerals to form new compounds, or by the dissolved components of the different minerals acting upon one another to form new compounds.

Through these processes of hydrolysis, chemical reaction between applied salt and soil mineral, and the reaction of the dissolved components of the different minerals, probably there are formed in the soil solution, salts of high solubility.

In the analysis of soil water extracts, drainage waters, etc., there are found, besides the $NO_3$ acid radical, the acid radicals $HPO_4$, $SO_4$, $HCO_3$, Cl, $SiO_3$, and the base radicals, Na, Mg, Ca, K, etc. These acids and bases could well combine to form such compounds, for instance, as $CaH_4(PO_4)_2$, $Na_2HPO_4$, $K_2HPO_4$, $NaHCO_3$, $Mg(HCO_3)_2$, $CaSO_4$, $Na_2SO_4$, NaCl, KCl, $CaCl_2$, etc.

That such compounds are formed and do exist in the soil solution to a more or less extent, can hardly be doubted. Both direct and indirect evidences strongly support the assumption. For instance, in those regions where the rainfall is small and the amount of leaching is consequently slight, such as in the arid regions, there is an accumulation of soluble salts near or at the surface soil, transported from below by the evaporation of the soil water. Such an accumulation of salts is designated as alkali conditions. Such alkali conditions would occur even in the humid regions were it not for the excessive and frequent rains which tend to wash away these soluble salts and thus prevent their accumulation. The soluble salts found wherever alkali conditions exist vary in number and composition, but in most arid countries the chlorides, sulphates, and carbonates of sodium, calcium, and magnesium, predominate. Several other salts are generally found but not in large amounts. In humid regions there are many cases known where seemingly alkali conditions exist. Cameron, (11) reports that a soil in Maryland near the Maryland Agricultural College contained the following salts in large quantities: $NaNO_3$, $KNO_3$, $Mg(NO_3)_2$, $Ca(NO_3)_2$,

(12) Bul. 30, Bureau of Soils, U. S. Dept. of Agr., 1905.
(11) Bul. 17, Bureau of Soils, U. S. Dept. of Agr., p. 36, 1901.

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$CaSO_4$, $CaCl_2$, etc. Stevenson and Brown, (12), have found that there are alkali spots in certain areas in Iowa which are composed mainly of $Ca(HCO_3)_2$, $Mg(HCO_3)_2$, $Na_2SO_4$, $NaNO_3$, etc.

In a very extensive investigation King, (13), found that the amount of water-soluble salts in soils was high, and varied with the type of soil, the fertility, or manurial treatment it had received, etc. The table below shows a typical example as to the magnitude of the salts recovered in the water extracts by the conventional method. These salts are composed of K, Ca, Mg, $NO_3$, $HPO_4$, $SO_4$, $HCO_3$, Cl, and $SO_2$.

*Table 6. Total Salts Recovered from the Surface Foot of Eight Soil Types, 1903.*

| | Pounds per million of dry soil. | Pounds per acre of dry soil. |
|---|---|---|
| Norfolk Sandy Soil | 182.02 | 654.4 |
| Selma Silt Loam | 226.94 | 788.6 |
| Norfolk Sand | 167.22 | 599.7 |
| Sassafras Sandy Loam | 199.70 | 682.3 |
| Hagerstown Clay Loam | 590.3 | 1,670.0 |
| Hagerstown Loam | 532.15 | 1,532.0 |
| Janesville Loam | 468.19 | 1,330.00 |
| Miami Loam | 419.23 | 1,301.00 |

It will be readily seen that the quantity of soluble salts dissolved into the water extract is really high. Of course the investigation does not show in what form these compounds exist in the soil, whether in solution or in solid form, but readily soluble. If these acids and bases, however, unite to form salts which have a high solubility, there is no reason to doubt why they should not be in solution.

In performing leaching experiments various investigators have found that the first portion of the water passing through the dry soil always contains a far greater concentration than the subsequent leachings. The subsequent leachings finally reach a low degree of concentration which tends to remain constant. The higher concentration of salts in the first washings is attributed by some investigators to the decrease in absorbtive power of the soil for the salts, due to the process of drying. It could be equally attributed to the presence of readily soluble salts.

Furthermore, that salts of high solubility may exist in the soil solution is further confirmed by the reaction that is conceived to take place between the soil and a soluble salt added. Thus, $Alx\ Fex\ Mgx\ Nax\ Ca(SiO_3)x\ (H_2O)x + 2KCl = Alx\ Fex\ Mgx\ Nax\ K_2(SiO_3)x\ (H_2O) + CaCl_2$. The $CaCl_2$ is assumed to be in solution.

The evidences, therefore, of the existence of salts of high solubility in the soil solution are very strong. The solubilities of some of the salts that are likely to occur in the soil solution are shown in Table 6.

(12) Bul. 157, Ia. Agr. Expt. Sta., 1915.
(13) Bul. 26, Bureau of Soils, U. S. Dept. of Agr., p. 67, 1905.

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*Table 7. Solubility of Various Salts at 20° C.*

| Name of Salt. | Grams of Salt dissolved in 100 gm. of water. |
|---|---|
| $NaNO_3$ | 83.7 |
| $KNO_3$ | 31.6 |
| $Ca(NO_3)_2$ | 54.8(19) |
| $Mg(NO_3)_2$ | 42.33(19) |
| $KCl$ | 34.07 |
| $NaCl$ | 35.82 |
| $CaCl_2$ | 74.00 |
| $K_2SO_4$ | 11.11 |
| $CaSO_4$ | ..... |
| $MgSO_4$ | 36.2 |
| $Ca(HCO_3)_2$ | ..... |
| $Mg(HCO_3)_2$ | ..... |
| $NaHCO_3$ | 9.60 |
| $CaH_4(PO_4)_2$ | ..... |
| $(NH_4)_2SO_4$ | 75.4 |

(19) at 18° C

Since the formation of these salts is comparatively slow and their accumulation to any extent is prevented by the excessive and frequent rains in the humid regions, their amount in the soil solution is relatively small and does not form a saturated solution, probably, not even at a low moisture content. Those of course that form a saturated solution are separated in the solid phase. At a high moisture content, therefore, these salts are diluted and would cause only a small lowering of the freezing point, but as the water content is reduced they become more concentrated and they would cause a correspondingly greater lowering of the freezing point. That is exactly what the experimental results show. Hence, the experimental data agree almost perfectly with the hypothesis.

The foregoing hypothesis, however, does not explain why the lowering of the freezing point increases in a geometric progression while the moisture content decreases in an arithmetic progression, and not follow a direct invere proportionality ratio, (approximately), as might be expected.

It must be stated, however, that also for this phenomenon, no definite and proved explanation can be offered. The following hypothesis, however, would seem worth considering.

It is assumed that a portion of the water found in the soil is inactive or unavailable and does not take part in dissolving the salts in the soil. How this portion of the water is rendered inactive and in what form it exists, cannot be asserted with certainty. There are two possible ways in which it might exist: (1), as loosely chemically combined water, and (2), as adsorbed water. In the first case the water might react with some of the components of the soil to form hydrolysed substances or hydrates. There is a great amount of evidence which goes to bear out this view. It is suggested by Muntz and Gaudechon, (14), that a part of the heat generated upon moistening dry soils is probably due to chemical combination between the water and some soil components. Clays, for instance, are believed to possess

(14) Ann. Sci. Agron. (3), 4, 393-443, 1909.

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in the highest degree the power to form substances of hydration. Dry hydrogels upon rewetting, are believed to enter into chemical combination with water in order to resume their colloidal state.

If the water is physically adsorbed it is conceived that it is removed from the liquid phase and becomes practically solid like water of crystallization. It becomes then inactive or inoperative in the same manner as when a solute is adsorbed.

In which form of the above the inactive water exists, cannot be stated definitely. It is very probable that it exists in both forms. But in whichever form it might exist, the assumption that it is inactive or unavailable to dissolve the salts tends to explain the results, at least partially. Thus, for example, assuming that a clay soil adsorbs or combines chemically with 15% of water, and that this clay at 36% moisture causes a lowering of the freezing point of 0.034°C, and at 18%, .955°C, then at the former moisture content there is 21% of water available to dissolve the salts in the soil, while in the latter case there is only 3% available for the same purpose. It would be natural, therefore, that the depression of the freezing point would be many times greater at the low percentage of moisture content than at the high, than would be expected from the difference of the total moisture content, just as the experimental data really indicate.

The foregoing hypothesis, therefore, would tend to explain, at least partially, why the lowering of the freezing point of the various types of soil with the exception of quartz sand and possibly some extreme types of sandy soil, should increase in a geometric progression while the percentage of water decreases in an arithmetic progression. It would also tend to explain why the lowering of the freezing point of quartz sand should increase inversely proportional with the water content, which would tend to indicate that quartz sand causes very little, if any, of the water to become inactive. That the latter fact might be so is further shown by the solidification which can be induced when the moisture content is only about 0.7%, practically at the air dry state.

Mention has already been made that in conducting a preliminary series of tests to ascertain how close the lowering of the freezing point of a soil sample could be duplicated it was found that at a high moisture content the duplicate readings would agree almost perfectly with one another for all types of soil but at a low moisture content the duplicate readings would agree with one another very close only with some soils, such as the quartz sand, kaolin, burned silicic acid, etc., but with other soils, such as the clay, loam, etc., the duplicate readings would vary appreciably, and indeed the first depression would be always greater than the second. This latter phenomenon was made of further special study by determining the lowering of the freezing point of a number of types of soil at low moisture content at successive freezings. The freezing process consisted of either allowing the soil sample to freeze at its proper freezing point and then thawing it by holding the tube containing the soil in the hand, or allowing the temperature of the soil to fall 3 or 4°C after it had frozen and then thawing it as before. Some of the results thus obtained are shown in Table 8. The magnitude of the decrease of the depression due to the successive freezings

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is not comparable either within the same soil or in different soil types, because the length of time and degree of freezing or super-freezing were not the same neither within the same soil nor in the different soils. These results are intended to show only that successive freezings tend to decrease the lowering of the freezing point of some soils and not of others.

*Table 9. Decrease of the Lowering of the Freezing Point with Successive Freezings.*

| Quartz sand. | | | Sandy loam. | | |
|---|---|---|---|---|---|
| Percentage of moisture. | Number of times frozen. | Lowering of the freezing point. | Percentage of moisture. | Number of times frozen. | Lowering of the freezing point. |
| 1.5 | 1 | .075 | 7.10 | 1 | .520 |
| | 2 | .077 | | 2 | .410 |
| | 3 | .076 | | 3 | .400 |
| | 4 | .075 | | 4 | .400 |
| | 5 | .073 | | | |
| Clyde Loam. | | | Clay. | | |
| 22 | 1 | .900 | 17.00 | 1 | 1.245 |
| | 2 | .700 | | 2 | 0.705 |
| | 3 | .620 | | 3 | .555 |
| | 4 | .560 | | 4 | .550 |
| | 5 | .555 | | 5 | .540 |
| Clay. | | | Burned Silic Acid. | | |
| 18.80 | 1 | .960 | 89.66 | 1 | .535 |
| | 2 | .855 | | 2 | .520 |
| | 3 | .665 | | 3 | .525 |
| | 4 | .600 | | 4 | .522 |
| Kaolin. | | | | | |
| 13.42 | 1 | 1.155 | | | |
| | 2 | 1.115 | | | |
| | 3 | 1.110 | | | |
| | 4 | 1.110 | | | |

It will be noticed that the lowering of the freezing point of quartz sand, burned silicic acid, and kaolin remains practically the same with successive freezings, but that of sandy loam, Clyde loam, and the two clays, becomes less with each repeated freezing and that the degree of diminution is very considerable, amounting in the clay soils to about 50% and in the sandy soil about 20%. This amount of decrease in depression, however, in the clays, loams, etc., would not have been so great had these soils not been cooled 3 or 4°C after they were frozen and kept at that low temperature for some length of time. The decrease has about reached its limit with all these soils as further freezings did not cause any important variations.

The question now is what causes this diminution of the lowering of the freezing point with successive freezings in the case of the agricul-

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tural soils and why a similar diminution does not occur in the more artificial substances. It must be admitted, however, that for this phenomenon also, no definite and proved explanation can be offered. The following suggestions, however, seems to deserve and warrant consideration.

It was first thought that the soil solution at the low moisture might have reached its saturation point in concentration and as it cooled, salts separated, for the solubility of the salts diminishes with falling temperature, and thus the solution became less concentrated. This hypothesis, however, would not explain the continued decrease in depression with repeated freezings, for if the soil solution were concentrated to the saturation point at the low moisture content all the excess of salts should separate the first time that it is cooled below O°C, and inasmuch as probably not all of the separated salts would go again into solution upon thawing—owing to the short length of time—the concentration of the solution and hence the lowering of the freezing point should remain more or less stationary. Hence, this hypothesis fails to explain the results.

If it is true that the soil adsorbs water and that this adsorbed water is removed from the liquid phase and becomes almost solid like water of crystallization and it no longer acts as a solvent of the salts in the soil, then the foregoing phenomenon on the diminution of the depression with repeated freezings might be explained under the following hypothesis: The adsorption of the water is due, at least in part, to the colloids in the soil. Upon freezing, these colloids coagulate and the bonds uniting them with the water break and the adsorbed water becomes liberated. This liberated adsorbed water becomes available and goes to dilute the original solution and thereby decreases the lowering of the freezing point. Thus, for instance, if there were only 5% of available moisture before the first freezing was made, there is probably 6% at the end of the first freezing, 7% at the end of the second freezing, and so on, until probably all or most of the colloids are coagulated. The coagulation is not complete in the first freezing but the greatest amount takes place in the first freezing and then smaller amounts in the successive freezings.

This hypothesis seems to find a large amount of confirmation from both direct and indirect evidences. It is now generally believed that there are present in soils both hydrosols and hydrogels consist of organic substances, the humus compounds, and inorganic substances, the hydrates of alumina, iron, manganese, hydrated silica, the zeolitic silicates, etc., that the hydrosols are continually being produced in the soils by physical action such as that of the water on clay, or by chemical changes such as the decomposition of silicates; and, that there are in nature various agencies such as changes in temperature, concentration of solution, etc., by which hydrosols are changed to hydrogels, and vice versa. Changes in temperature are known to produce especially very marked effects upon these colloids. Both heating and freezing have been found to cause coagulation of the hydrosols and hydrogels and that this coagulation is accompanied by a decrease in the absorbtive

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power. It has been abundantly proved, for example, that when clay is heated its absorbtive power for water is greatly diminished.

This hypothesis, therefore, would seem to explain very well the diminution of the depression of the freezing point of the agricultural soils at low moisture content with repeated freezings. It would seem also to suggest that the artificial substances, such as the quartz sand, burned silicic acid, and kaolin, either do not contain colloidal material, or if they do, it is not coagulable.

At the high moisture content coagulation of the colloids of the agricultural soils should also take place, but since the amount of water present is high, and the solution is relatively very dilute, the amount of water that is released upon coagulation is too small to make any noticeable effect upon the depression.

In late years a great amount of work has been done upon the effect of steam heat on the solubility of soil constituents. Especially important and valuable are the investigations of Russel and Hutcheson, (15), and Lyon and Bizzel, (16), upon the subject. These investigators, as well as others subsequently, found that in general, steam heat increased the ammonia content as well as the water-soluble inorganic matter.

In order to show the applicability of the freezing point method on this subject and also to ascertain to what degree the steam heat increases the concentration of the solution, the lowering of the freezing point of a few types of soil steam heated, was determined. The general procedure consisted of taking soils from the field, bringing them up to a high moisture content, and then dividing each soil into two parts, one part was used as a check and the other part was steam heated in an autoclave for about 3 hours at a pressure of 15 atmospheres. After steaming, the moisture content was brought up to the original and the lowering of the freezing point was determined. The following table contains the depression of the freezing point of the unsteamed and steamed portions of each soil. Only a very limited number of soil types was employed because it was desired to show mainly the applicability of the method on the subject.

*Table 9. Effect of Steam Heat on the Lowering of the Freezing Point of Sojls.*

| Name of Soil. | Lowering of the Freezing Point. |
|---|---|
| Sandy loam unsteamed | .020 |
| Sandy loam steamed | .035 |
| Clay unsteamed | .030 |
| Clay steamed | .045 |
| Clyde loam unsteamed | .040 |
| Clyde loam steamed | .115 |
| Peat unsteamed | .015 |
| Peat steamed | .065 |

It will be at once seen that steam heat increased the lowering of the freezing, and consequently the concentration, in every soil, but the

(15) Jour. Agr. Sci. 2, 411, 1908.
(16) New York Cornell Sta., Bul. 275, 1910.

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magnitude of the increase is by far greater in those soils in which the organic matter is very high or predominates, than in the mineral soils. Apparently steam heat causes a greater amount of material to go into solution in the former than in the latter classes of soil.

Besides employing the freezing point method to determine the concentration of the soil solution in the soil at various moisture contents, it can also be used, of course, to measure the salt content of alkali soils. Through the kindness of Dr. F. S. Harris of the Utah Agricultural College we were able to secure soil samples of alkali, irrigated and non-irrigated soils. All these soils could be classed as heavy sandy loams. The lowering of the freezing point obtained from these soils is shown in the following table.

*Table 10. Lowering of the Freezing Point of Alkali, Irrigated, and Non-irrigated Soils of the Arid Region.*

| Name of Soil. | Percentage of moisture. | Lowering of the Freezing Point. |
|---|---|---|
| Alkali | 27.23 | 1.950°C |
| Non-irrigated | 16.36 | .320 |
| Irrigated | 17.72 | .210 |

It will be readily seen that the depression and hence the concentration of salts in solution are very great in the alkali soil, even at such high moisture content, almost at the saturation point; at a low moisture content the depression was so great that it could not be read on the scale of the thermometer. The depression of the non-irrigated soil is greater than that of the irrigated even though the moisture content of the latter is greater than that of the former. The magnitude of the depression in both cases, however, is small due to the high water content present.

In conclusion, then, it must be stated that if it is to be accepted that the lowering of the freezing point of soils at the different moisture contents represents actual concentration of solution, then many extremely important and far-reaching consequences follow. (1). The soil solution is not under all conditions dilute as is generally believed. It is dilute only at the high moisture content but at a low moisture content it is tremendously concentrated and its concentration can be increased by the application of soluble salts. (2). The concentration of the soil solution does not remain constant but varies tremendously with the moisture content and the amount of soluble salts applied. (3). The solution of normal soils in humid regions may never reach a saturation point, at least with most salts. (4). The magniture of concentration of solution is not the same for all soils, but varies greatly with the different soils. (5). The absorbtive power of the soil does not seem to influence at all the concentration of the solution; those soils known to possess the highest absorbtive power generally contain a very high concentration of solution and those that have a low absorbtive power possess a low concentration of solution. Hence, the two prevailing theories regarding the concentration of the soil solution are diametrically opposed by the results of this investigation.

Furthermore, the acceptance that the lowering of the freezing point

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at the low moisture contents represents actual concentration of solution throws a new and important light on the subject of the wilting coefficient of plants. The wilting of plants has heretofore been generally attributed to their inability to take up the water which is held by the soil with a great attractive force. While this explanation is undoubtedly correct and especially if it is true that some of the water is loosely chemically combined or physically adsorbed and consequently removed from the liquid phase, yet if the great depression of the freezing point at the low moisture content represents concentration of solution, then the wilting of plants must be also influenced by plasmalytic phenomena. As already seen, the calculated concentration amounts in some cases to over 28,000 p. p. m., which is equivalent to an osmotic pressure of over 12 atmospheres. At a still lower moisture content these magnitudes would be far greater. When it is considered that the osmotic pressure of the cell sap of such common agricultural plants as wheat, barley, oats, corn, generally amounts to only about 5 atmospheres under humid conditions then the possibility of the wilting of plants in some soils at least being partly due to the plasmolytic phenomena, becomes greatly strengthened. Again, the best standard nutrient solutions contain an osmotic pressure of only between 1.50 and 1.75 atmospheres. Knops standard nutrient solution and the more recent one proposed by Shive, (17), contain an osmotic pressure of 2.75 and 1.5 atmospheres, respectively.

It would seem very possible, therefore, that in some soils at least, especially in the complex types where the depression of the freezing point is greatest, the concentration of the solution probably plays a very important part in the wilting of plants.

Again, if the concentration of the soil solution varies tremendously with the moisture content, then it becomes at once obvious that the centifuge and paraffin oil methods can give some information concerning the concentration of the soil solution only at the moisture content at which the extraction can be made. Even at that moisture content, however, the concentration of the extracted water is only approximately close to the total concentration of the entire moisture in the soil, if the theoretical principles already discussed (p. 6) are correct.

Finally, it must be stated that the freezing point method with further development promises of furnishing a quantitative comparison of the soluble salt content in different soils and thereby give an idea as to their degree of fertility. In its present stage it can only compare the concentration or salt content of the soil solution at different moisture contents of the same soil, and between very extreme types of soil. The moisture content seems to be the controlling factor and the development of the method towards being employed to compare quantitatively the salt content and probably the fertility of different soils, lies in standardizing the moisture content, and this phase of the work is now under investigation.

(17) Plant World, 1915.

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Effect of Application of Soluble Salts Upon the Concentration of the Soil Solution in the Soil.

Our present knowledge concerning the effect of application of soluble salts upon the concentration of the soil solution in the soil is extremely unsatisfactory. A great amount of experimental work has been done upon the subject but the conclusions drawn therefrom are not at all concordant. This is undoubtedly due to the fact that there has been no method of attacking the problem directly and consequently the studies had to be conducted indirectly. As a result of this difficulty many of the present views concerning the effect of application of soluble salts upon the concentration of the soil solution in the soil have been deduced from *a priori* consideration from certain physical laws of solutions and physical properties of soils. According to the theory advanced many years ago by Whitney and Cameron, (18), the application of soluble salts such as KCl would probably not increase the concentration of the soil solution. They based their theory upon the law of equilibrium of solutions. Their studies with water extracts led them to believe that the soil solution is saturated or nearly saturated in respect to the soil constituents, and the application of such soluble salts with which the solution is already saturated would merely force back the dissociation and thus re-establish equilibrium. The concentration of the soil solution, therefore, tends to remain constant.

According to the absorption-adsorption theory the concentration of the soil solution may not be increased by the application of soluble salts. It is maintained that these phenomena of absorption-adsorption tend to maintain a practically constant concentration of solution for any given soil. Indeed, it is asserted that it is these properties of the soil which prevent the soil solution from becoming too concentrated either upon withdrawal of moisture or application of salts to the soil.

(18) Bul. 22, Bureau of Soils, U. S. Dept. of Agr., 1903.

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| | n/100 KCl | | | | n/100 $K_2SO_4$ | | | | n/100 MgSO$_4$ | | | | n/100 $(NH_4)_2SO_4$ | | | | n/100 $Ca(NO_3)_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. |
| | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | |
| Purified Quartz | .370 | .370 | 0 | 0 | 100. | .250 | .248 | .002 | 0.80 | 99.20 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |
| Unpurified Quartz | .370 | .380 | .010 | 2.70 | 97.30 | .250 | .240 | .010 | 4.00 | 96.00 | .130 | .128 | .002 | 1.54 | 98.46 | .243 | .243 | 0 | 0 | 100.0 |
| Sandy loam | .370 | .320 | .050 | 13.51 | 86.49 | .250 | .155 | .095 | 38.00 | 62.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .160 | .083 | 34.16 | 65.84 |
| Silt loam | .370 | .282 | .088 | 23.78 | 76.22 | .250 | .112 | .138 | 55.20 | 44.80 | .130 | .112 | .018 | 13.85 | 86.15 | .243 | .122 | .121 | 49.79 | 50.21 |
| Silt loam | .370 | .285 | .085 | 22.97 | 77.03 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .115 | .015 | 11.54 | 88.46 | .243 | .125 | .118 | 48.56 | 51.44 |
| Clyde loam | .370 | .262 | .108 | 29.19 | 70.81 | .250 | .050 | .200 | 80.00 | 20.00 | .130 | .070 | .060 | 46.15 | 53.85 | .243 | .090 | .153 | 62.96 | 37.04 |
| Red Clay | .370 | .275 | .095 | 25.68 | 74.32 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .105 | .025 | 19.23 | 80.77 | .243 | .130 | .113 | 46.50 | 53.50 |
| Gray Clay | .370 | .295 | .075 | 20.27 | 79.73 | .250 | .055 | .195 | 78.00 | 22.00 | .130 | .055 | .075 | 57.70 | 42.30 | .243 | .160 | .083 | 34.16 | 65.84 |
| Peat | .370 | .305 | .065 | 17.57 | 82.43 | .250 | .180 | .070 | 28.00 | 72.00 | .130 | .120 | .010 | 7.69 | 92.31 | .243 | .183 | .060 | 24.69 | 75.31 |
| Kaolin | .370 | .340 | .030 | 8.11 | 91.89 | .250 | .205 | .045 | 18.00 | 82.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |

| | n/100 KCl | | | | n/100 $K_2SO_4$ | | | | n/100 MgSO$_4$ | | | | n/100 $(NH_4)_2SO_4$ | | | | n/100 $Ca(NO_3)_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. |
| | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | |
| Purified Quartz | .370 | .370 | 0 | 0 | 100. | .250 | .248 | .002 | 0.80 | 99.20 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |
| Unpurified Quartz | .370 | .380 | .010 | 2.70 | 97.30 | .250 | .240 | .010 | 4.00 | 96.00 | .130 | .128 | .002 | 1.54 | 98.46 | .243 | .243 | 0 | 0 | 100.0 |
| Sandy loam | .370 | .320 | .050 | 13.51 | 86.49 | .250 | .155 | .095 | 38.00 | 62.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .160 | .083 | 34.16 | 65.84 |
| Silt loam | .370 | .282 | .088 | 23.78 | 76.22 | .250 | .112 | .138 | 55.20 | 44.80 | .130 | .112 | .018 | 13.85 | 86.15 | .243 | .122 | .121 | 49.79 | 50.21 |
| Silt loam | .370 | .285 | .085 | 22.97 | 77.03 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .115 | .015 | 11.54 | 88.46 | .243 | .125 | .118 | 48.56 | 51.44 |
| Clyde loam | .370 | .262 | .108 | 29.19 | 70.81 | .250 | .050 | .200 | 80.00 | 20.00 | .130 | .070 | .060 | 46.15 | 53.85 | .243 | .090 | .153 | 62.96 | 37.04 |
| Red Clay | .370 | .275 | .095 | 25.68 | 74.32 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .105 | .025 | 19.23 | 80.77 | .243 | .130 | .113 | 46.50 | 53.50 |
| Gray Clay | .370 | .295 | .075 | 20.27 | 79.73 | .250 | .055 | .195 | 78.00 | 22.00 | .130 | .055 | .075 | 57.70 | 42.30 | .243 | .160 | .083 | 34.16 | 65.84 |
| Peat | .370 | .305 | .065 | 17.57 | 82.43 | .250 | .180 | .070 | 28.00 | 72.00 | .130 | .120 | .010 | 7.69 | 92.31 | .243 | .183 | .060 | 24.69 | 75.31 |
| Kaolin | .370 | .340 | .030 | 8.11 | 91.89 | .250 | .205 | .045 | 18.00 | 82.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |

| | n/100 KCl | | | | n/100 $K_2SO_4$ | | | | n/100 MgSO$_4$ | | | | n/100 $(NH_4)_2SO_4$ | | | | n/100 $Ca(NO_3)_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. |
| | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | |
| Purified Quartz | .370 | .370 | 0 | 0 | 100. | .250 | .248 | .002 | 0.80 | 99.20 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |
| Unpurified Quartz | .370 | .380 | .010 | 2.70 | 97.30 | .250 | .240 | .010 | 4.00 | 96.00 | .130 | .128 | .002 | 1.54 | 98.46 | .243 | .243 | 0 | 0 | 100.0 |
| Sandy loam | .370 | .320 | .050 | 13.51 | 86.49 | .250 | .155 | .095 | 38.00 | 62.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .160 | .083 | 34.16 | 65.84 |
| Silt loam | .370 | .282 | .088 | 23.78 | 76.22 | .250 | .112 | .138 | 55.20 | 44.80 | .130 | .112 | .018 | 13.85 | 86.15 | .243 | .122 | .121 | 49.79 | 50.21 |
| Silt loam | .370 | .285 | .085 | 22.97 | 77.03 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .115 | .015 | 11.54 | 88.46 | .243 | .125 | .118 | 48.56 | 51.44 |
| Clyde loam | .370 | .262 | .108 | 29.19 | 70.81 | .250 | .050 | .200 | 80.00 | 20.00 | .130 | .070 | .060 | 46.15 | 53.85 | .243 | .090 | .153 | 62.96 | 37.04 |
| Red Clay | .370 | .275 | .095 | 25.68 | 74.32 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .105 | .025 | 19.23 | 80.77 | .243 | .130 | .113 | 46.50 | 53.50 |
| Gray Clay | .370 | .295 | .075 | 20.27 | 79.73 | .250 | .055 | .195 | 78.00 | 22.00 | .130 | .055 | .075 | 57.70 | 42.30 | .243 | .160 | .083 | 34.16 | 65.84 |
| Peat | .370 | .305 | .065 | 17.57 | 82.43 | .250 | .180 | .070 | 28.00 | 72.00 | .130 | .120 | .010 | 7.69 | 92.31 | .243 | .183 | .060 | 24.69 | 75.31 |
| Kaolin | .370 | .340 | .030 | 8.11 | 91.89 | .250 | .205 | .045 | 18.00 | 82.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |

| | n/100 KCl | | | | n/100 $K_2SO_4$ | | | | n/100 MgSO$_4$ | | | | n/100 $(NH_4)_2SO_4$ | | | | n/100 $Ca(NO_3)_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Percentage of Original Concentr. of Salt Solution Went to Concentrate Soil Solution. |
| | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | | °C | °C | °C | | |
| Purified Quartz | .370 | .370 | 0 | 0 | 100. | .250 | .248 | .002 | 0.80 | 99.20 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |
| Unpurified Quartz | .370 | .380 | .010 | 2.70 | 97.30 | .250 | .240 | .010 | 4.00 | 96.00 | .130 | .128 | .002 | 1.54 | 98.46 | .243 | .243 | 0 | 0 | 100.0 |
| Sandy loam | .370 | .320 | .050 | 13.51 | 86.49 | .250 | .155 | .095 | 38.00 | 62.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .160 | .083 | 34.16 | 65.84 |
| Silt loam | .370 | .282 | .088 | 23.78 | 76.22 | .250 | .112 | .138 | 55.20 | 44.80 | .130 | .112 | .018 | 13.85 | 86.15 | .243 | .122 | .121 | 49.79 | 50.21 |
| Silt loam | .370 | .285 | .085 | 22.97 | 77.03 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .115 | .015 | 11.54 | 88.46 | .243 | .125 | .118 | 48.56 | 51.44 |
| Clyde loam | .370 | .262 | .108 | 29.19 | 70.81 | .250 | .050 | .200 | 80.00 | 20.00 | .130 | .070 | .060 | 46.15 | 53.85 | .243 | .090 | .153 | 62.96 | 37.04 |
| Red Clay | .370 | .275 | .095 | 25.68 | 74.32 | .250 | .105 | .145 | 58.00 | 42.00 | .130 | .105 | .025 | 19.23 | 80.77 | .243 | .130 | .113 | 46.50 | 53.50 |
| Gray Clay | .370 | .295 | .075 | 20.27 | 79.73 | .250 | .055 | .195 | 78.00 | 22.00 | .130 | .055 | .075 | 57.70 | 42.30 | .243 | .160 | .083 | 34.16 | 65.84 |
| Peat | .370 | .305 | .065 | 17.57 | 82.43 | .250 | .180 | .070 | 28.00 | 72.00 | .130 | .120 | .010 | 7.69 | 92.31 | .243 | .183 | .060 | 24.69 | 75.31 |
| Kaolin | .370 | .340 | .030 | 8.11 | 91.89 | .250 | .205 | .045 | 18.00 | 82.00 | .130 | .130 | 0 | 0 | 100.0 | .243 | .243 | 0 | 0 | 100.0 |

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| | n/10 $NaNO_3$ | | | | n/10 $KH_2HPO_4$ | | | | n/10 $CaH_4(PO_4)_2$ | | | | n/10 $Na_2HPO_4$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. | Depression of Solution alone. | Depression of Solution with Soil. | Difference. | Percentage of change in Depression. |
| | °C. | °C. | °C. | | °C. | °C. | °C. | | °C. | °C. | °C. | | °C. | °C. | °C. | |
| Purified Quartz | .370 | .368 | .002 | .054 | .120 | .117 | .003 | 2.50 | .070 | .068 | .002 | 2.86 | .180 | .177 | .003 | 1.67 |
| Unpurified Quartz | .370 | .360 | .010 | 2.70 | .120 | 0 | .120 | 100.0 | .070 | .002 | .068 | 97.14 | .180 | .003 | .177 | 98.33 |
| Sandy loam | .370 | .325 | .045 | 12.16 | .120 | .002 | .118 | 98.33 | .070 | .002 | .068 | 97.14 | .180 | .025 | .155 | 86.11 |
| Silt loam | .370 | .332 | .038 | 10.27 | .120 | .005 | .115 | 95.83 | .070 | 0.0 | .070 | 100.0 | 0 | | | 13.89 |
| Silt loam | .370 | .345 | .025 | 6.76 | .120 | .006 | .114 | 94.16 | .070 | 0 | .070 | 100.0 | 0 | | | |
| Clyde loam | .370 | .277 | .093 | 25.14 | .120 | .007 | .113 | 5.84 | .070 | 0 | .070 | 100.0 | 0 | | | 7.22 |
| Red Clay | .370 | .333 | .037 | 10.00 | .120 | .008 | .112 | 93.33 | .070 | 0 | .070 | 100.0 | 0 | | | 5.55 |
| Gray Clay | .370 | .330 | .040 | 10.81 | .120 | 0.0 | .120 | 100.0 | 0 | 0 | 0 | 0 | 0 | | | 6.12 |
| Peat | .370 | .275 | .095 | 25.68 | .120 | .070 | .050 | 41.67 | .070 | .045 | .025 | 35.72 | .180 | .110 | .070 | 38.89 |
| Kaolin | .370 | .340 | .030 | 8.11 | .120 | .075 | .045 | 37.50 | .070 | .055 | .015 | 21.43 | .180 | .115 | .065 | 36.11 |
| | | | | 99.95 | | | | 97.50 | | | | 97.14 | | | | 63.89 |
| | | | | 97.30 | | | | 0 | | | | 2.86 | | | | |
| | | | | 87.84 | | | | 1.67 | | | | 2.86 | | | | |
| | | | | 89.73 | | | | 4.17 | | | | 0 | | | | |
| | | | | 93.24 | | | | 5.84 | | | | 0 | | | | |
| | | | | 74.86 | | | | 6.67 | | | | 0 | | | | |
| | | | | 90.00 | | | | 0 | | | | 0 | | | | |
| | | | | 89.19 | | | | 58.33 | | | | 35.72 | | | | |
| | | | | 74.32 | | | | 62.50 | | | | 78.57 | | | | |
| | | | | 91.89 | | | | | | | | | | | | |

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which would be detrimental to the growth of plants. Through the absorption-adsorption phenomena, salts are given up to the soil solution when the latter becomes dilute, or salts are withdrawn from it when it becomes concentrated and thus a constant equilibrium is maintained.

Since it was found that by means of the freezing point method the concentration of the soil solution can be measured directly in the soil, it was at once suggested that this method might be used to study directly the effect of application of soluble salts upon the concentration of the soil solution in the soil. The results thus directly obtained ought to show definitely whether or not the concentration of the soil solution in the soil can be increased by application of soluble salts.

The procedure consisted of treating different types of soil with n / 100 solution of various salts, allowing them to stand in room temperature and saturated atmosphere for about 24 hours, and then determining the lowering of their freezing point. To each soil sample was added a sufficient amount of a solution to bring it up to a very high moisture content, thus eliminating some of the errors that occur at the low moisture content. For each treated sample there was always a check having the same percentage of moisture, but made up only of water. Great care was taken to mix each soil sample with the solution or water, very thoroughly. The results obtained are detailed in table 11,

*Table 11. Effect of Application of Soluble Salts upon the Concentration of the Soil Solution in the Soil.*

Before entering into the discussion of the foregoing data, an explanation as to their form of presentation is necessary. The first column to the left of each salt solution contains the lowering of the freezing point of the solution itself; the second column contains the lowering of the freezing point of soil treated with the solution, and, this lowering is entirely due to the solution applied, as the amount of depression due to the soil itself at that moisture content has been subtracted; the third column shows the difference in the depression of the solution before and after it is added to the soil; the fourth column contains the percentage of change in the depression that the salt solution suffered in the soil; and, the fifth column shows what percentage of the original concentration of the salt solution went to increase the concentration of the soil solution.

With this explanation, the above data showing the influence of application of soluble salts upon the concentration of the soil solution in the soil may now be considered. An examination of the figures in the fifth column of the various salt solutions shows many remarkable facts. Starting with the KCl solution it will be seen that from 70.81 to 100% of the concentration of the salt solution went to concentrate the soil solution. The concentration of the soil solution is increased greatest in quartz sand, kaolin, sandy loam, and peat, and least in humus loam.

Considering next the $K_2SO_4$ solution it will be seen that a much smaller percentage of the concentration of this salt solution went to increase the concentration of the soil solution of the various soils. With the exception of quartz sand and kaolin, where the increase is

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99.2 and 78.0%, respectively, the increase in the other soil is comparatively small, amounting in the case of humus loam to only 20%, gray clay 22%, red clay 42%, etc. It is interesting to note that in the red clay the concentration is 20% greater than in the gray clay. Evidently, therefore, the influence of $K_2SO_4$ upon the concentration of the soil solution of the various soils is not as great as that of KCl.

The solution of $MgSO_4$ increased the concentration of the soil solutions of some soils quite appreciably, but in others only a very small amount. Thus, in the quartz sand, sandy loam, silt loams, kaolin, and peat the greatest part if not all of the original concentration of this salt solution went to concentrate their soil solutions but in gray clay, humus loam, and red clay, a smaller portion of the original concentration was used for the same purpose.

The $(NH_4)_2SO_4$ solution increased the concentration of the soil solution of the agricultural soils on the average much less than the $MgSO_4$ but considerably more than the $K_2SO_4$. It will be seen that in the quartz sand and kaolin fully the entire concentration of the salt solution was added to their solution, but in the other agricultural soils only about half of the original concentration was imparted to their soil solutions.

The increase in concentration of the soil solution of the various soils by the $Ca(NO_3)_2$ and $NaNO_3$ solutions is extremely interesting. It will be noted that in all the soils, with the exception of peat and humus loam, practically the entire concentration of these two salt solutions was added to their soil solutions and the percentage of the $Ca(NO_3)_2$ is appreciably greater than that of the $NaNO_3$. The failure of both clays to decrease at all the concentration of $Ca(NO_3)_2$ is of especial interest.

Of all the compounds used, the phosphates increased the concentration of the soil solution of the agricultural soils the least. Indeed, it will be seen that with the exception of quartz sand, peat, and kaolin, the concentration of the solution of the other soils was increased from 0.0 to only 8.78% of the original concentration of $K_2HPO_4$, $CaH_4(PO_4)$, and $Na_2HPO_4$ solutions. Of the three solutions the last caused the greatest increase in the contentration which is only about 8%. Evidently these compounds have very little if any effect upon the concentration of the soil solution of most agricultural soils.

In order to ascertain whether greater concentrations than n / 100 of these phosphate compounds would increase the cencentration of the soil solution a normal solution of each was employed. The lowering of the freezing point of n / 1 $Na_2HPO_4$ solution, however, could not be determined on account of its saturation point and the consequent precipitation, and, therefore, no calculation could be made to what extent it influenced the concentration of the soil solution. The following table, therefore, contains only the results obtained with n / 1 solution of $K_2HPO_4$ and $CaH_4(PO_4)_2$ in red clay.

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*Table 12. Effect of Normal Solutions of $K_2H\ PO_4$ and $CaH_4\ (PO_4)_2$ Upon the Concentration of the Soil Solution of Red Clay.*

| Name of Solution. | Depression of solution alone. | Depression of solution with soil. | Difference. | Percentage change in depression of solution. | Percentage of concentration if original solution went to concentrage soil solution. |
|---|---|---|---|---|---|
| $K_2HPO_4$..... | 1.900 | .275 | 1.625 | 85.5 | 14.5 |
| $CaH_4(PO_4)_2$..... | .630 | .073 | .557 | 88.4 | 11.6 |

These results show that by increasing the concentration to n/1 a greater percentage of the concentration goes to increase the concentration of the soil solution of the clay than when n/100 strength is used, but the amount of increase, however, is small in comparison with the strength of the salt solution used.

This part of the investigation goes to show, therefore, that the different compounds employed have an entirely different effect upon the concentration of the soil solution of the various types of soil. In the case of the neutral salts the soil solution was increased from 20 to 100% of their strength added, while in the case of the phosphate salts very little if any of their concentration was imparted to the soil solution of the agricultural soils.

The contention of the two theories already mentioned that the concentration of the soil solution tends to remain constant and is in equilibrium with the soil and that the application of soluble salts may not increase this concentration, are not entirely confirmed or borne out by the data of this investigation. The only compounds which do not seem to cause an increase in the concentration of the soil solution are the phosphates, and that is only in certain soils.

The question now is: How is this increase in concentration of the soil solution by the soluble salts brought about? And, what is the composition of the resulting soil solution?

As already stated the lowering of the freezing point indicates only total concentration, and it tells nothing of the reactions that might take place between the soil and solution, or of the composition of the resulting soil solution. To obtain an answer to the above question, or questions, therefore, it is necessary to resort to other means.

In the study of adsorption or fixation of salts by soils one of two methods is generally employed: (1), either to shake a certain amount of soil with an excess amount of solution, and analyse the supernatant liquid, or, (2), to pass through a column of soil, a salt solution and analyse the percolate. These studies have shown that in the case of neutral salts the amount of the base of the salt solution added is diminished and an equivalent or nearly equivalent amount of other bases are dissolved in the solution. Thus, if a soil is treated with a solution of KCl the amount of K in the resulting solution is diminished but is replaced by an almost equivalent amount of other bases such as Ca, Mg, etc., while the amount of Cl remains practically unchanged.

In explanation of this phenomenon two theories have been proposed. One is based upon a chemical reaction between the soil and solution

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with an exchange of bases, and the other is based upon a physical selective adsorption of the base of a salt with a resulting acid which dissolves an equivalent amount of the soil bases. In the first theory it is assumed that a neutral salt reacts with the polysilicates of the soil with the base becoming fixed or insoluble and an equivalent amount of another base being replaced thus: Alx Fex Mgx Nax $Ca(SiO_3)x$ $(H_2O)$ + 2KCl = Alx Fex Mgx Nax $K_2(SiO_3)x$ $(H_2O)$ + $CaCl_2$. This equation typifies the metathetical reaction that may take place between a neutral salt and the zeolitic compound of the soil. The $CaCl_2$ is supposed to be in solution.

The fixation of the soluble phosphates is supposed to be accomplished by the bases present in the soil, such as iron, aluminum, tetanium, lime, and magnesium. The reaction which is different from the above is typified by the following equation:

$CaH_4(PO_4)_2 + CaCO_3 = Ca_2H_2(PO_4)_2 + CO_2 + H_2O$.

$Ca_2H_2(PO_4)_2 + CaCO_3 = Ca_3(PO_4)_2 + CO_2 + H_2O$. The soluble phosphate, therefore, reacting with calcium forms insoluble $Ca_3(PO_4)_2$.

According to the physical selective adsorption theory it is suggested that when a soil is in contact with a solution such as KCl it adsorbs the potassium ions at a much greater rate or greater proportion then the chlorine ions thereby, (since an equivalent number of hydroxyl ions are also removed with the potassium ions), causing a partial hydrolysis of the solution, (KCl + HOH = KOH (adsorbed) + HCl), and leaving free acid in the solution which goes to dissolve the soil bases.

Although the last theory might be correct, yet it has not been absolutely proven and does not account for all the facts. The first or chemical theory, however, which seems more rational, explains practically all the facts quite satisfactorily and is probably more widely accepted. In the light of this theory the foregoing question: How is the increase in concentration of the soil solution by the soluble salts brought about? and, What might be the composition of the resulting soil solution?, are explainable, at least partially. For instance, the increase in concentration of the soil solution may not be due to the direct addition of the concentration of the salt solution but that a new compound or compounds might be formed which are in solution and have smaller than or as great lowering of the freezing point as the salt solution added, and that not any of the salt solution added may exist in the original form in the resulting soil solution.

It would be a remarkable coincidence, however, if a new compound was formed in the various mineral soils to which $Ca(NO_3)_2$ was added, which had a lowering of the freezing point as great as this salt solution itself. In a case of this character one is almost led to believe that the entire concentration of this salt solution was simply added to the soil solution without undergoing any change, just as in the case of quartz sand, where the increase in concentration of its solution is due to the direct addition of the concentration of the salt solution.

The almost complete disappearance of the original concentration of $CaH_4(PO_4)_2$, $Na_2HPO_4$, and $K_2HPO_4$ solutions in some of the soils tends to confirm the equation already given that these compounds react with the bases of the soils and form insoluble substances and thus the con-

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centration of the soil solution is not at all increased either directly by these compounds or by the formation of new compounds as in the case of neutral salts.

As far as the results of the phosphates are concerned in most of the agricultural soils, they agree with the theory of Whitney and Cameron that the concentration of the soil solution may not be increased by the addition of these compounds, but the explanation, does not appear to be the same.

But as far as the results of the neutral salts are concerned they agree neither with the theory of these investigations nor with the absorption-adsorption theory which postulates that the properties of absorption-adsorption of the soil tend to maintain a constant concentration of solution.

## SUMMARY.

The study of the concentration of the natural soil solution is of the greatest importance as well as of the highest interest from all standpoints—the chemical, physical, physiological, and biological. Our knowledge concerning the concentration of the natural soil solution has heretofore been obtained through indirect means, as there has been no method capable of measuring it directly as it exists in the soil and consequently its exact magnitude has not been known, especially under different conditions, including variation in moisture content, fertilizer treatment, tillage, season, etc.

In the present paper the freezing point method has been suggested as a new means of measuring the actual concentration of the soil solution in the soil at different moisture contents and under different treatments. The method is based upon the general principle that the freezing point of water is lowered by the presence of soluble material and that the degree of lowering is proportional to the amount of the soluble material present, (non-electrolytes). The procedure consists of placing a short column of soil in a glass tube 1 inch in diameter and 9 inches long, inserting the bulb of a Beckmann thermometer into this column of soil, then putting this soil tube into another larger glass tube and allowing the soil mass to cool in a cooling bath at a temperature of —4.5°C. After the soil mass has supercooled to about 1°C, the thermometer is jarred or moved in the soil whereupon solidification commences and the mercury thread begins to rise and continues to do so until the proper freezing point is reached where it remains for some time and then begins to fall again. The highest temperature reached on the thermometer is taken as the proper freezing point of the soil.

It has been found that it is extremely easy to determine the lowering of the freezing point of soils. The solidification can be started when the soil mass is supercooled to only about 0.3°C and it is far easier to induce solidification in soils than in solutions. The depression of the freezing point of soils can be measured from any maximum water content down to a very low water content. The minimum water content probably lies slightly below the wilting coefficient of plants. In the case of quartz sand, for instance, the lowering of the freezing point can be measured when the moisture content is only about 0.7%.

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The lowering of the freezing point has been determined in a large number of soils at two different moisture contents, low and high. The results of this study show that at the high moisture content the freezing point lowering of all the different types of soil examined is very low and varies only slightly in the different soils. At the low moisture content, however, the lowering of the freezing point is very high and varies tremendously with the extreme types of soil, being highest in clay type and lowest in sand. The amount of concentration and osmotic pressure that are represented by the great depressions in the complex types of soil, are indeed very great. The depression of .955°C of clay, for instance, which was obtained at 18.80% moisture content, represents a concentration of 28,941 p. p. m., and an osmotic pressure of 12.04 atmospheres.

In all the soils, with the exception of quartz sand and some extreme types of sandy soil, the ratio of the lowering of the freezing point is not directly inversely proportional to the ratio of the water content, as might be expected, (approximately), but the former is many times greater than the latter. Thus, in the case of clay the inverse ratio between the lowering of the freezing point and the water content is 27 to 1.85, respectively. Upon investigating this relation more thoroughly by determining the lowering of the freezing point of various soils at a large number of moisture contents it was found that this relation follows a mathematical law and indeed the geometric law, i. e., the lowering of the freezing point increases in a geometric progression while the water content decreases in an arithmetic progression. In the case of quartz sand and some extreme types of sandy soil, however, the depression of the freezing point increases inversely proportional with the water content.

The enormous concentration which the lowering of the freezing point of some soils represents at the low moisture content created at first some doubt as to whether this lowering of the freezing really represents concentration or is caused by some physical factor such as the supposed pressure with which the water films are held by the soil particles, etc. All possible physical factors that might enter into the freezing point have been thoroughly considered but it has not become apparent that the great depressions have been caused by any physical agent. On the contrary all evidences, both direct and indirect, point overwhelmingly to the fact that these high depressions of the freezing point are produced by and represent actual concentration. Thus, washed quartz sand which would not be expected to possess a solution of high concentration causes a lowering of the freezing of only .070°C at 1.5% moisture content, while clay, which would *a priori* be considered as containing a solution of high concentration produces a depression of the freezing point of .955°C at 18.80% moisture content. The rate of increase in the lowering of the freezing point with the decrease in moisture content is uniform throughout, from the maximum to the minimum moisture content, etc.

In explaining that the high depression of the freezing point at the low moisture content, or the increase of the depression of the freezing point with the decrease in moisture content, might represent concen-

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tration of solution, the following suggestion is tentatively offered: It is assumed that the soil solution contains salts or their ions, produced by the reaction of the dissolved components of the soil minerals, hydrolysis of the minerals, application of fertilizers, decomposition of organic matter, etc. These salts have, as a rule, a high solubility and would require a large amount of them to form a saturated solution. They are formed relatively slowly and since the frequent and excessive rains, especially in the humid regions, tend to leach them away, only a relatively small amount of them is present at a time. At a high moisture content these salts are diluted and the lowering of the freezing point is small. As the moisture content, however, is reduced, they are concentrated and the lowering of the freezing point becomes greater.

A critical consideration of the character of the soil system and a thorough examination of the available data of the soil solution as obtained through soil water extracts, drainage water, etc., lend considerable support to this hypothesis.

The foregoing hypothesis, however, does not explain why the lowering of the freezing point increases in a geometric progression while the water content decreases in an arithmetic progression and not follow an inverse proportionality law (approximately) as might be expected.

In explanation of this fact the hypothesis is also offered that some of the water contained by the soil might be either loosely chemically combined or physically adsorbed, or both, in which event that portion of the water is not free or available to dissolve the salts in the soil, but is entirely removed from the liquid phase. If it is physically adsorbed it is conceived that it is almost solid like water of crystallization. The hypothesis would seem to explain the results. Thus, for example, if a soil like clay causes 15% of water to become unavailable, or be removed from the liquid phase, and at 36% moisture this soil gives a depression of the freezing point of .034°C and at 18.8% moisture, .955°C, then at the first case there is 20% moisture to dissolve the salts while in the second case there is only 3% of moisture for the same purpose. The depression of the freezing point at the low moisture content, therefore, would be many times greater than that at the high moisture content, than should be expected from the total percentages of moisture content.

While no experimental proof is offered for the above hypothesis there are data which seem to point towards its validity. Thus, it has been observed that at a low moisture content the lowering of the freezing point of all colloidal soils employed, becomes less or smaller with successive freezings. This phenomenon might be explained under the supposition that at least part of the unavailable water is adsorbed by the colloids of the soil. Through the process of freezing this colloidal material is coagulated and thereby releases the adsorbed water which becomes free or available and goes to dilute the original solution.

In the event, therefore, that the lowering of the freezing point at the different moisture contents represents actual concentration of solution, then many extremely important and far-reaching consequences follow: (1). The soil solution is not under all conditions dilute as is generally believed. It is dilute only at the high moisture content, but

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at a low moisture content and in some soils, it is tremendously concentrated, and this concentration can be increased with the application of soluble salts. (2). The concentration of the soil solution does not remain constant but varies greatly with the moisture content, and the amount and kind of soluble salts added. (3). The soil solution of normal soils in humid regions may never reach a saturation point, in all the salts at least. (4). The magnitude of the concentration of the soil solution is not the same for all soils but varies greatly with the different soils. (5). The absorbtive power of the soils does not seem to influence at all the concentration of the soil solution. Those soils known to possess the highest absorbtive power generally contain a solution of very high concentration, while those that have a low absorbtive power contain a low cencentration of solution. (6). The wilting of plants at a low moisture content may not be entirely due to their inability to obtain the remaining moisture in the soil, but also to the plasmolytic effects of the high concentration of the soil solution.

By means of the freezing point method the effect of application of soluble salts upon the concentration of the soil solution in the soil, was also studied. The compounds were added to the soil in solution in n/100 strength and consisted of KCl, $K_2SO_4$, $MgSO_4$, $(NH_4)_2SO_4$ $Ca(NO_3)_2$, $NaNO_3$, $K_2HPO_4$, $CaH_4(PO_4)_2$, and $Na_2HPO_4$. The soils consisted of washed quarts sand, two different kinds of silt loam, and clay, and one kind of sandy loam, humus loam, peat, and kaolin. The results obtained in this study show that all these compounds have an entirely different effect upon the concentration of the soil solution of the different soils. In the case of the neutral salts the concentration of the soil solution was increased from 20 to 100% of their strength employed, while in the case of the soluble phosphates the concentration of the soil solution of all the soils except peat, quartz sand, and kaolin, was extremely little, if any, increased. These results on the whole do not confirm entirely the theories that the application of soluble salts, even in small amounts, may not increase the total concentration of the soil solution.

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TECHNICAL BULLETIN NO. 25. MARCH, 1916.

# MICHIGAN AGRICULTURAL COLLEGE

## EXPERIMENT STATION

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## BOTANICAL DEPARTMENT

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# THE LEAF-SPOT DISEASE OF TOMATO

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BY

EZRA LEVIN

Under direction of E. A. BESSEY and G. H. COONS

EAST LANSING, MICHIGAN
1916.

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## FOREWORD.

The importance of the tomato crop in the state of Michigan and the seriousness of some of the losses occasioned by diseases led the Department of Botany to begin investigations on the subject several years ago. The investigation of one of these diseases, the leaf-spot, the subject of this bulletin, was turned over to one of the advanced students, Mr. Ezra Levin, who began work in the fall of 1913 and devoted a very large part of the following school year and summer to the problem. The work was carried out along lines laid down by Dr. G. H. Coons, Research Assistant in Plant Pathology, who kept very close supervision of Mr. Levin's work. The revision of the manuscript and the larger part of the preparation of the Bibliography were also carried out by Dr. Coons. The result of the investigations throw great light upon the structure and life history of the fungus (*Septoria lycopersici*) causing the disease and explain many of the apparently contradictory observations and conclusions of previous investigators. They are of especial value as they show where lie the vulnerable points in the life history of the fungus, an item of the utmost importance in the combating of a disease. Furthermore, the facts learned have been found to shed light upon other diseases caused by other species of Septoria, such as the late blight of celery, etc.

In view of the foregoing it is believed that it is highly desirable to publish the details of the investigations as a Technical Bulletin, for the benefit of investigators wherever the diseases of this type are being studied, and to present the main facts, together with directions for control, in a popular form in another publication.

ERNST A. BESSEY,
Botanist.

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# THE LEAF-SPOT DISEASE OF TOMATO.

## THE HOST.

The common commercial type of tomato is *Lycopersicon lycopersicon* (L.) Karst., and is to be distinguished from the currant tomato, *Lycopersicon pimpinellifolium* Dunal, and the cherry tomato, *Lycopersicon cerasiforme* Dunal.

The importance of the tomato crop in the United States is indicated by the following statement from the Thirteenth Census Report: "Judged by value, tomatoes were the most important vegetable, the value exceeding $13,700,000 in 1909." The Michigan tomato crop is extremely valuable. The report credits the state with $217,256, tomato production, and this has since increased to at least five times this amount.

The methods used in growing this crop influence the prevalence of this disease to a great extent.

Seed is sown in hot beds or greenhouses several weeks before setting out; (in Michigan from March to May). In the open, two types of culture are employed: (1) training of plants to two or three stems tied to a stake, (2) allowing plants to grow over the ground at will. In forcing tomatoes, the plants are usually trained to a single stem and staked.

In recent years more and more complaints, indicating the prevalence of serious tomato diseases, have come from the tomato growers of Michigan. The plant disease survey of the state indicated that Septoria leaf-spot was especially serious. Investigation was begun by the writer in September, 1913, and practically completed August, 1914.

## THE DISEASE.

The common names by which this serious disease is known are: "late blight," "blight," and "leaf-spot." It is, however, a well known fact that in some sections of the country, tomatoes are attacked by *Phytophthora infestans* (Mont.) de By., the cause of late blight of potato. This precludes the use of "late blight" as a name for this disease. "Blight" and "leaf-spot" are also more or less preempted. The former of these terms or preferably "early blight" may best be associated with *Alternaria solani* (E. and M.) J. and G. which also attacks tomatoes. A common usage among pathologists seems to warrant the name of "leaf-spot" in referring to the diseases of this type.

## PREVIOUS INVESTIGATION OF THE DISEASE AND ITS CAUSAL ORGANISM.

It is generally conceded that the fungus, *Septoria lycopersici* Speg. causes the disease commonly known as "leaf-spot" of tomato. As will be seen this has been more of an inference based upon the constant asso-

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ciation of the organism with the disease than a conclusion resulting from experimentation.

The organism was discovered in Argentina by Spegazzini in 1882. The fungus and its characteristic lesions were tersely described by him in a publication containing descriptions of several other organisms. The name given by Spegazzini has been in common use for this disease-producing organism although the fungus was subsequently found upon the host in countries far from the source of the type material.

The early accounts of this disease consisted of a few scattered notes recording the finding of the fungus in various localities. For example, as recorded in Briosi and Cavara (1889): Cuboni (1888) and Passerini (1889) found the fungus in Italy. Passerini's contribution is noteworthy in that this author recognized the pathogenic character of the organism and outlined rather fully the symptoms of the disease.

B. D. Halsted (1896; 1897) was the first to report the disease for the United States and in one of his annual reports he listed *Septoria lycopersici* for New Jersey and mentioned it as causing one of the leading fungous diseases of tomato. A. D. Selby (1897a) discussed a "new arrival" in Ohio, apparently *Septoria lycopersici,* and in a later article, its distribution in Ohio was particularly noted (1897b). The same author in 1899 stated—"During the season 1898 conditions of warmth and moisture seemed to favor the development of the Septoria fungus." In 1899, Dr. E. A. Bessey observed extensive damage in Maryland near Annapolis Junction (verbal communication). F. S. Earle (1900) noted a serious epidemic of this disease in the cold frames at Auburn, Ala. N. A. Cobb (1902), discussing tomato diseases of Australia, stated that this disease, "has never been mentioned in this journal (Agr. Gaz. N. S. Wales) hitherto." "The leaves are attacked more particularly although there is hardly any part of the plant entirely free from attack." Again recording the fungus for Australia, D. McAlpine (1903) gave a description of the fungus and the effect produced upon the host. W. A. Kellerman (1903) wrote a brief note on *Septoria lycopersici.* In 1904, W. A. Orton mentioned the disease as serious in the previous year. G. Delacroix (1905) in recording the history of this fungus in France, wrote a description of the causal organism on the host and in pure culture and noted successful infection experiments. (See page 12). L. Reh (1905) described the disease in Germany. G. Köck (1905) noted the disease in Austria. Later he described *Septoria lycopersici,* and made a series of observations on its effects on the host, and resistance of varieties. K. Kornauth (1905) gave a further account of the disease in Austria. J. Burtt-Davy (1905) records the disease from Transvaal. J. L. Sheldon, in West Virginia (1905), noted "Leaf-Spot." B. F. Floyd (1905), in Missouri, described the disease as attacking "leaves, stems, and sometimes green fruit." L. Hollos (1907) described the disease in Hungary. F. D. Kern noted *Septoria lycopersici* in 1906 in Indiana. H. T. Güssow (1908) gave a full description of the disease. This article, dealing chiefly with greenhouse conditions, is an extensive discussion of the fungus and the disease which it produces. The symptoms of the disease are discussed in detail, inconclusive inoculation experiments are reported, and various inferences as to the dissemination of the organism are drawn. F. L. Stevens and J. G. Hall (1909) used *Septoria lycopersici* for experi-

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ments reported in a paper entitled "Variation of Fungi due to Environment." This article is chiefly devoted to a biometric study of Septoria fruiting bodies but from it more or less of a description of the organism in pure culture can be gleaned. The Great Britain Agriculture and Fisheries Board (1909) again drew attention to the disease in a popular article taken largely from Güssow's. H. W. Barre (1910) noted the disease and its importance in South Carolina. J. W. Lloyd and I. S. Brooks (1910), Illinois, gave a brief descriptfon of "Leaf-Spot." H. S. Reed (1911) reported damage done by the organism in Virginia and gave the most complete description of field conditions of the disease up to that time. Long (1913) gave a popular account of the disease under English conditions. J. B. S. Norton (1914), discussing the disease in Maryland, gave the results of spraying experiments, as well as a summary of the previous spraying tests of other stations.

## ECONOMIC IMPORTANCE.

That this disease has long been of importance in different parts of the world is apparent from the reports of N. A. Cobb (1902), D. McAlpine (1903), G. Köck (1905), and H. T. Güssow (1908), to which reference has already been made.

In the United States the disease has spread more or less rapidly, particularly within the last few years. The damage resulting from it ranges from three percent to a total loss of the crop. Practically all the states that raise tomatoes to any degree commercially are more or less troubled with leaf-spot, as is shown by the accompanying map (Figure 1) which summarizes data obtained by a questionnaire, addressed to American pathologists.

The following comments taken from the replies are interesting:

J. B. S. Norton, of Maryland, in answer to the questionnaire states: "The disease causes a loss of 10-25 per cent of our tomato crop. The loss will run into hundreds of thousands of dollars, if not a million." For Missouri, Geo. M. Reed writes: "In some fields perhaps 50% of the early tomato crop is damaged by this disease." N. J. Giddings, of West Virginia: "It is the worst disease which we have on tomatoes in West Virginia." C. E. Durst, of Illinois, states: "This disease coupled with Fusarium Wilt is almost driving the growers out of the business of tomato growing in that section (southern Illinois)." C. W. Edgerton, Louisiana, writes: "Not as yet common but seems to be spreading rapidly. I look for this disease to become serious in this state." It is noteworthy that Septoria leaf-spot has evidently appeared in Louisiana but recently. H. S. Reed (1905): "The culture of tomatoes in southwestern Virginia is becoming increasingly difficult, due to the serious blight and point rot diseases, which have attacked this crop annually for the past five years." On the contrary, H. W. Anderson, Wabash College, Indiana, writes: "In this region we consider it a benefit, since it kills off the leaves near the base of the plant and allows the sun to ripen the tomatoes."

## DISTRIBUTION.

In answer to a questionnaire as to prevalence, the pathologists of thirty-four states reported the disease as *common* from the following: Ala-

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bama, California, Connecticut, Delaware, Illinois, Louisiana (becoming common), Maryland, Michigan, Missouri, New Jersey, New York, North Carolina, Pennsylvania, and Wisconsin. (Figure 1).

A reply to a similar request to the Bureau of Plant Industry, Plant Disease Survey (Cotton and Truck Disease and Sugar Plant Investigations) for information as to the distribution of the disease brought the following: "Reported in 1903 from Alabama, Connecticut, Missouri, New Jersey, New York, and Ohio; 1904 from North Carolina and Ohio; 1905 from Delaware, Maryland, North Carolina, Ohio, and West Virginia; 1906 from Delaware, Nebraska, New Jersey, Ohio, and West Virginia; 1907 from Delaware, Illinois (mentioned that it has been present in this state for three or four years), Maryland, Nebraska, New Jersey, North

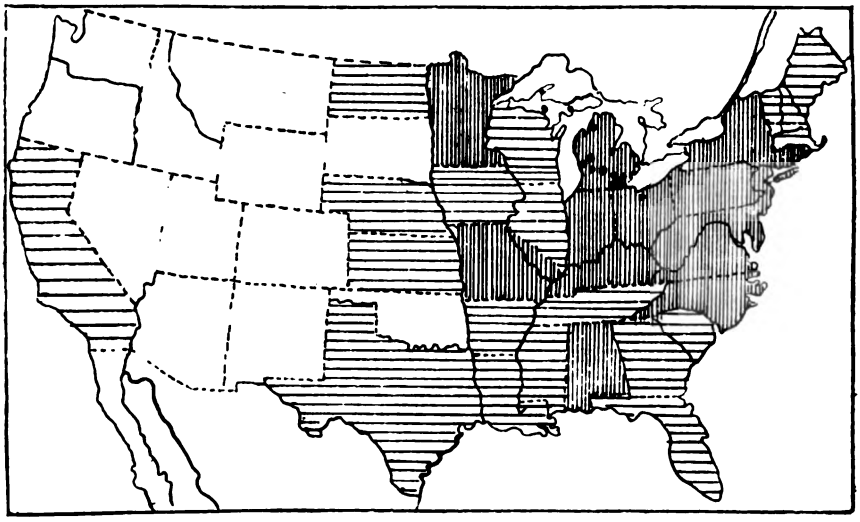

Figure 1. Distribution and relative importance of the Septoria leaf-spot of Tomato, as determined from a questionnaire to American phytopathologists. Collection records from Michigan are shown by dots.

Carolina, Ohio, and West Virginia; 1908 from Delaware, Maryland, New Jersey, Ohio, Pennsylvania, and South Carolina; 1909, Delaware, Indiana, Iowa, Maryland, Nebraska, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, and West Virginia; 1910 from Delaware, Indiana, Kansas, Kentucky, (exceptionally prevalent), Maryland, Mississippi, Nebraska, New York, Ohio, South Carolina, Texas, Virginia, and West Virginia; 1911 from Delaware, District of Columbia, Florida, Illinois, Iowa, Maryland, Massachusetts, Missouri, Ohio, Pennsylvania, Virginia, West Virginia and Wisconsin; 1912 from Alabama, Delaware, District of Columbia, Illinois, Indiana, Iowa, Maryland, Michigan, Minnesota, Missouri, New Jersey, North Carolina, Ohio, Rhode Island, South Carolina, Tennessee, Texas, Virginia, and West Virginia." The reply also notes that "The disease may not necessarily have progressed as rapidly as this would indicate but may have been present in all the states earlier."

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SIGNS.

The general signs of this tomato disease are conveyed by the popular term, "blight." The growers notice a general unthriftiness in their plants, along with a dying of the leaves beginning first with the lower ones and gradually advancing upward on the plant. (Plate 1). The fruit fails to ripen evenly or rapidly, and with severe attack, the entire crop may fail. Such fruit as is produced from diseased plants, lacks sweetness and solid matter. This last condition is often complained of by canners, although they ascribe "watery" tomatoes to wet season, rather than to a fungous disease made severe by the season. In short, all the general signs which accompany interference with the photosynthetic function are to be expected with this disease. The great reduction in leaf surface is accompanied by a reduction of carbohydrate formation.

Along with these general signs of the disease there are distinct lesions on various parts of the plant which allow sure diagnosis.

The fungus causes lesions upon the leaf, the stem, the fruit and the calyx.

*On the Leaves:*

The earliest indication of the disease is a water-soaked spot which can be distinguished with a hand lens on the underside of the leaf. There is no noticeable discoloration of the tissue at the outset. As the spot grows larger it becomes more or less circular in outline and shows a definite margin. The affected tisssue darkens, becomes shrunken and later appears hard and dry. The color of this spot may vary from black to grayish-white. The spots may vary in shape and size from a small circular spot of pin-head size to a large irregular spot of about 2 cm. in diameter. Not infrequently the spots coalesce. While the tissue is shrinking 3-10 small, black, glistening pycnidia appear in the spot. Finally, yellowish, mucilaginous masses can be seen exuding from the pycnidia. Upon microscopic examination these are found to be masses of long filiform spores. The number of pycnidia in the larger spots may be as high as 30. The pycnidia are well defined, visible with the naked eye and separate (Plate 2.). Pycnidia may occur on the under side of the leaf; usually, however, they occur on the upper side. At this point it must be noted that not all spots contain pycnidia when the leaf dies. This point will be taken up in detail later. (Page 24).

About the time of spore exudation, the green tissue of the leaflet contiguous to the fungous spot begins to turn yellow. This yellowing increases, eventually involving the entire leaflet. Then the fungous spots which have so far been pliable become dry and brittle. The leaflets gradually droop and dry on the stalk which later also shrivels up but remains attached to the stem until broken off by a slight jar. On tomatoes which are staked the disease is sometimes confined to the lower leaves (Plate 1). Where the plants are allowed to trail at will, the disease may cause almost complete defoliation of the plant, the small tufts of young, terminal leaves alone escaping.

*On the Stems:*

The disease is commonly found on the stems. It is manifested by small, slightly elongated, dark spots containing pycnidia. These spots

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are not so clearly defined as those on the leaf. The damage to the stem is slight; these spots do not enlarge to form cankers and are not serious except insofar as they produce spores for further infection.

*On the Calyx:*

Small spots, more or less elongated, occur on the calyx and take a form intermediate between those on the leaves and stems. It may be remarked that the differences in form of the spot are doubtless due to the texture of the host.

*On the Fruit:*

The disease has never been seen in Michigan as affecting the fruit in the field, however, J. B. S. Norton, (1914) states, "The disease may also attack the fruit, causing dark spots." It will be seen later that artificial inoculation with spores does not lead to infection of fruit, unless the epidermis is ruptured. In general it may be noted that the damage to the fruit by leaf-spot is negligible.

## ETIOLOGY OF THE DISEASE.

*Previous Work:*

H. C. Delacroix (1905) states, "In September, 1904, several attempts at infection were made. The inoculation made on the leaves without wound, simply by placing the spores on them, did not succeed except when the surrounding air was thoroughly saturated, and under these circumstances, I was successful with but one infection. The eight which I tried to inoculate by a very slight scratch on the leaf gave better luck, the infection resulting under these conditions were five out of eight attempts." The only other recorded attempt to determine the pathogenicity of this fungus was performed by H. T. Güssow (1908). "A water infusion of diseased leaf tissue sprayed on a healthy plant." "The whole foliage, stem and young fruits were covered with spots." From the meager experiments of Delacroix the impression that the organism is merely a wound parasite would be justified while the experiment of Güssow is inconclusive.

*Formal Proof of Causation:*

(a) Constant association of organism with the disease:

Suspected "leaf-spot" material was collected from Earliana tomatoes in the Botanical greenhouse. The typical spots were examined. Pycnidia were found containing long, filiform, septate spores. Comparing this material with descriptions of the fungus from various sources, the fungus was diagnosed as *Septoria lycopersici* Speg.

(b) Pure culture:

A pure culture was obtained by the ordinary dilution methods. The material was carefully washed under a steady, fine stream of sterile distilled water. Pycnidia were crushed on a slide and plates were poured. These were incubated; later single colonies were transferred to nutrient agar. Several days later, these were examined; pycnidia were found in abundance, but no spores were present. Portions of mycelium were transferred to nutrient glucose agar, potato agar, and tomato agar. In eight days pycnidia were found containing typical, long, filiform spores. Subcultures on the same media were made and spores produced in such

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quantities that the white, glistening mass exuding from the pycnidia was easily perceptible to the unaided eye. This was very fortunate as spores could be obtained free from the mycelium and the other substratum. (See Plate 4).

(c) Production of the disease on healthy plants by inoculation from culture.

A mass of exuding spores from pure culture was shaken up in sterile, distilled water. In the first attempt to produce the disease, thirty-two plants were used.[1] Sixteen plants selected as checks, were sprayed with sterile, distilled water from a DeVilbiss atomizer No. 2. The spore suspension was sprayed upon the other sixteen plants in the same manner, using a similar atomizer. These were all kept under bell jars.

The result was positive but spots on the inoculated plants were very few per leaflet and small. One check plant also showed infection. Many leaflets showed no spots at all, and others showed no more than two. Considering the number of spores applied, and comparing the results with the Van Tieghem cell in which 30% of the spores had germinated, the results were not highly satisfactory.

The following experiment was performed. By means of a platinum loop a drop of spore suspension was placed upon a single leaflet; a very small piece of "White Rose" cotton was quickly spread over it. Twenty-five such inoculations were made. The plants were placed in a moist chamber, in which there was an arrangement to produce a fine mist when desired.[2] In five days every leaflet inoculated showed typical, water-soaked, diseased areas. The uninoculated leaflets were free from disease. Pycnidia were evident after ten days and exudation of white spore masses thirteen days after inoculation. The advantages of this method of inoculation were: the spores were protected by the cotton since the moisture collecting on the leaves did not remove them; the cotton indicated exactly where the inoculation was made; every uninoculated leaflet was a check on the inoculated leaflet.

(d) Reisolation and (e) Reinoculation:

Plates were poured from the exuding spore masses from the pycnidia and reisolations were made to tomato agar, nutrient agar, and potato agar. The identity of the recovered organism was determined beyond question. The cultures so obtained were used successfully in subsequent inoculation experiments.

*Infection Phenomena:*

The Period of Incubation:

Numerous experiments gave entirely concordant results as to the time necessary after inoculation for noticeable lesions to appear. In the extensive experiment reported on page 33 the daily observation required in this experiment gave abundant opportunity for exact record. The first signs of the spots appeared five days after inoculation. In experiments where inoculations were made on media of various kinds and these media incubated among the inoculated plants to insure more or less similarity of conditions, it is noteworthy to observe that the colony on tomato agar was approximately the same size as the spot on the leaf.

[1] This work was done in a greenhouse where the temperature varied from 18° C. to 25° C, and the ordinary moist greenhouse conditions prevailed.

[2] A fine jet of water from the tap was allowed to strike the top of a large galvanized iron box.

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This set of phenomena indicated that the initial attack of the fungus produces little effect on the host, and it is only after several days that the fungus, probably by its by-products kills the tissues. While no work has been done with the by-products of this fungus, it may be mentioned that coincident with the killing of the host tissue occurs the darkening of the tomato agar. Experimentation with such products would undoubtedly yield results, opening up a practically untouched field of Plant Pathology.

The Subsequent Development:

On the sixth day submerged pycnidia could be seen in the inoculated leaf. The record with media was similar. On the eighth day the pycnidia were erumpent. Sections at this time showed that spore formation was beginning. On the thirteenth day exudation of spores occurred and this was taken as an indication of maturity of the spores. The record with media paralleled this with the exception that the spore exudations were more extensive in the moist test tube.

Infection and Moisture:

In the experiments so far reported in testing the pathogenicity of the fungus the inoculated plants were left in the moist chamber—sometimes in a chamber filled with a fine spray—for a comparatively long period. Experiments were later inaugurated to find the approximate number of hours requisite in the moist chamber to insure infection.

Previous experiments had shown that 100% infection followed the placing of viable spores on the under side of leaves. The flecks of cotton were found valuable as a marker and as a device for preventing the washing of the spores from leaf to leaf. Five leaflets each of ten strong vigorous plants about 7-14 inches tall were inoculated with spores from the stock pure culture. Nine[3] of these plants were put in the Wardian case which was provided with a jet of water which struck the top and broke into a fine spray. A plant was taken out at intervals of 6, 12, 24, 36, 48, 54, 60, and 72 hours after inoculation. Each plant was immediately dried by the breeze from an electric fan. After an interval of 15 minutes these plants were placed on a shelf in the window of the laboratory. After five days all plants showed typical spots on the inoculated leaves. The other leaves were healthy. That plant which had not been put into the moist chamber showed as typical a case of infection as the others. This experiment is in striking variance to the usual experience with plant pathogenes, since it is commonly stated that the host must be wet for a number of hours at least in order for infection to occur.

On account of this contradiction the experiment was immediately repeated with exactly similar results. The technique of the two experiments was alike with the exception that in the second experiment the plants were kept in the blast of the fan, following removal from the moist chamber, until infection was evident. No variation from the normal time was observed.

An experiment was then performed in which six small plants fresh from the greenhouse were inoculated respectively on the upper and lower leaf surfaces with a loop of spore suspension. The atmosphere in the greenhouse was such that the plants were in a condition of incipient wilting and the water drop disappeared at once. (August, 1914). These

[3]One plant was not put into the moist chamber.

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plants were then set in the direct sunlight on a shelf in the window. Five of these plants showed typical infection.

This experiment was repeated using for inoculation the spore mass without making a suspension in water. With a platinum needle a minute portion of this spore mass exuding from a pycnidium was transferred to the leaflets of five plants. The results were similar. All plants were infected after five days. This experiment was performed because it was thought that the drop of spore suspension evaporating, drew the spores into the substomatal chamber. The results indicate that this hypothesis is untenable.

The interpretation of this experiment is rather difficult. There can be no doubt that an extremely small amount of water is necessary to enable the spores to germinate and enter the tissues. This water may be the small amount held upon the leaves, but this is difficult to credit in view of the experiment just reported. The moist air of the substomatal chamber may be concerned. The mucilaginous spore wall undoubtedly clings tenaciously to a small amount of imbibed water. A fact to be taken into consideration in the interpretation of these results is that the spores do not germinate in less than 24 hours in a Van Tieghem cell or on a moist slide. Combining this with these experiments, the results appear most striking. It is possible that the temperature factor is important in this phenomenon.[4] It is evident that if the spore reaches the leaf, regardless of the agent involved, the spore will cause infection, providing the temperature is favorable for the development of the mycelium. It may be that in the case of other fungi as well, current ideas on the necessity of water films and dew for long periods in order to produce infection may be based wholly upon inference.

## PHYSIOLOGICAL AND ECOLOGICAL RELATIONS OF THE CAUSAL ORGANISM.

*Germination:*

To observe the spore germination and subsequent colony formation in various media, the following method was employed: Petri dishes containing Van Tieghem cells were arranged according to Duggar's (1910, p. 59) method. Blotting paper was perforated so that small glass rings would be held in place while being sterilized. (Plate 3, Fig. 1). The media used were cornmeal agar (see appendix), potato glucose agar, nutrient broth, nutrient glucose agar, tomato leaf agar, and distilled water. Solid media, from which hanging drops were made, was melted and cooled to approximately 42° C. An exuding mass of spores was shaken up in each tube. Each Petri dish as described above contained seven Van Tieghem cells. A different medium was used in each Petri dish. Each hanging drop of the medium contained 4-6 spores.

Thus it was possible to make germination studies and observe development (under the microscope) until the organism had attained macroscopic size. The exact time elapsing before germination was difficult to determine, due to the manner of development of the spores. The first signs are manifested in a pronounced swelling of the spore to almost twice the original diameter. Regular, well-defined vacuoles appeared surrounded by dense protoplasm, which made the spore look

[4]These experiments were performed from August 15 to 31.

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like a chain. This condition appeared in all the media at the end of twenty-four hours. At the end of 36 hours the end cells of the spores had grown somewhat irregular, slightly tapering, and somewhat narrower than the middle cells. The elongation of both ends of the spore preceding the formation of definite germ tubes was of general occurrence (Plate 9, Fig. 3). Exceptions to this were seen when the number of spores in the hanging drops was increased so that the spores touched.

After 48 hours, germ tubes were formed varying from 1 to 4 for each spore. The germ tube may grow from any cell. (Plate 9, Figs. 1 and 2).

One may consider the germination of the spores as beginning either with the formation of the definite germ tube or with the growth from the terminal cells. In many spores instead of developing germ tubes immediately, the terminal cells elongate and then branch. The other cells in the spore may or may not send out germ tubes. For the first four days, the germination phenomena and initial colony formation are much alike in various media (Plate 9, Figs. 4 and 5). With the subsequent growth, differentiation takes place.

In the Van Tieghem rings with nutrient glucose agar and potato glucose agar a very luxuriant growth took place. The four-day-old colonies were readily visible to the unaided eye. The hyphae were richly branched, with prominent oil drops, and were very striking because of their irregular contour. (Plate 9, Fig. 7, Plate 8, Fig. 5). After six days, the medium became brown, and after eleven days, the mat-like stroma was so thick that observation with a microscope was impossible.

In distilled water the ring cultures made but slight growth other than germination and no sporulation was seen.

Cornmeal agar and tomato-leaf agar gave a moderate growth in marked contrast to the media rich in sugars. After four days, secondary spores—long filiform structures arising from small papillae on the mycelium—were found in tomato-leaf agar and two days later in the cornmeal agar. After eleven days, some of the threads of mycelium became dense brown. (Plate 9, Fig. 6). This condition was found in both cornmeal and tomato-leaf agar. (Plate 8, Fig. 4). Pycnidium formation was noticeable after the eleventh day. (Plate 9, Fig. 8).

In nutrient broth cultures, a diffuse rapid growth took place. The hyphae were narrow and regular, and were not profusely branched. On the sixth day, secondary spores were found. Five days after formation it was found that these secondary spores had germinated forming new colonies. (Plate 8, Fig. 3). Others produced secondary spores immediately after elongation (Plate 8, Fig. 2). After eleven days pycnidium formation was evident throughout the culture.

The observations may be summarized as follows:

1. Spore structures, evidently secondary spores, are formed abundantly in various media. These may germinate and form new colonies. This contradicts Delacroix (1900) who states, "The stylospores germinate easily in water and nutritive liquids by the production of a septate, branching filament *without* the formation of secondary spores."[5]

2. The presence of a distinct type of mycelium; whether this mycelium is a special stroma or pycnidial mycelium has not been definitely de-

[5]As the nutritive liquids used were not mentioned, repetition of Delacroix's experiment was not possible.

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termined. It is believed that these hyphae (as a base) become associated with the hyaline hyphae to form the pycnidial wall. It might be mentioned that all media become strongly browned immediately after the pycnidia begin to form. The source and nature of this browning must remain for future investigation.

*Growth on Media:*

Macroscopic Cultural Observation:

The following media were used: Cornmeal agar, nutrient glucose agar, prune juice agar, tomato agar, nutrient saccharose agar, nutrient broth, bean pods, potato plugs, tomato leaves, tomato stems, cornmeal and rice.

Spores from pure culture were inoculated into three tubes of double distilled water so that a microscopic examination gave about 36 spores in a loop. One loop of spore suspension was introduced in each tube of media. This experiment was carried on in triplicate, one tube being sealed with sealing wax,[6] three tubes of each medium making up one series. Five of these series were arranged. These were allowed to grow at room temperature for 48 hours; Series 1 was placed in the greenhouse under the plants that were severely affected with the disease (Approximately room temperature); Series 2 in the ice box, (Approximately 12°); Series 3 in 37½°; Series 4 (room temperature, about 21° C.) on shelf in the window of the laboratory; Series 5 (room temperature) diffused light.

In the accompanying table the growth on different media for 3, 6, 8, 10, 12 and 18 days respectively is described for Series 1. Series 3 made no growth whatever at 37 ½° and after ten days was placed at room temperature but did not revive. All the other series were so nearly identical that it is needless to differentiate between them. The organism made no growth on bean pods. Tomato agar and cornmeal agar were found to be the best media. In the former the growth simulated more closely than in any other medium, the growth on the leaf. The excessive stroma production found in other media was absent. The pycnidia were separate and distinct, the development almost identical as to the time necessary for pycnidia production after inoculation. The tomato agar seemed to inhibit the growth of molds and bacteria when plates were poured from field material. The use of the autoclaved tomato leaf was also very satisfactory, although here no definite spots or colonies were formed, the growth being diffuse.

The following table gives the result of this experiment:

[6]Reported on page 23.



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TABLE 1. GROWTH OF *SEPTORIA LYCOPERSICI* ON VARIOUS MEDIA:

| Media. | 3 Days. | 6 Days. | 8 Days. | 10 Days. | 12 Days. | 18 Days. |
|---|---|---|---|---|---|---|
| Tomato agar | Colonies slightly larger than after 48 hrs.; mycelium scanty, medium beginning to darken; indefinite brownish spots in colonies. | Increased growth; colony 3 mm. diam. distinct black pycnidia submerged 4-7 per colony, separate. | Pycnidia larger; mycelium slightly increased; more pycnidia forming. Darkening of medium mycelium submerged. | No stroma, pycnidia glistening, erumpent, mycelium no increase. | White spore masses exuding from pycnidia perceptible to naked eye. Spore masses as large as pycnidium. | Spore masses increase in size. Growth stopped. |
| Corn-meal agar | Colonies no larger, but turning brown, medium beginning to darken. Mycelium both submerged and aerial. | Mycelium slightly increased, brownish green, slight evidence of pycnidial formation. | Pycnidia distinct, submerged; separate, mycelium slightly increased. | Pycnidia larger, still submerged. Mycelium scanty and very dark. | Pycnidia slightly erumpent, glistening black, all mycelium darkened, colonies distinct. | Spores exuding. Grayish white masses with pycnidia separating from the colony sitting on the surface. |
| Nutrient Glucose agar | Darkening of medium. Abundant mycelium, spreading, dark except on edge of colony. | Growth raised, spreading; mycelium below surface scanty. Pycnidia formation very abundant, contiguous; colonies coalescing. | Pycnidia erumpent, black mycelium only seen on edge of colony. Entire growth made up of pycnidia. | Pycnidia erumpent, grayish black, surrounded by aerial mycelium. No increase in colony growth. | Several exuding spore masses. Mycelium grayish dirty white. | Spores exuding, grayish white masses abundant. Colonies erumpent, separate. Pycnidia contiguous. |
| Prune Juice agar | Abundant mycelium, slightly spreading, aerial, white. | Medium darkening, mycelial stroma becoming erumpent, mycelium slightly spreading in definite dark spots. | Pycnidia formation submerged in stroma, contiguous, stroma very erumpent, not spreading. | Mycelium darkened, stroma formation. Evidence of pycnidial formation. | Black erumpent pycnidia. No mycelium in evidence. | Spores exuding, white masses from a few pycnidia. |
| Tomato Stem | No signs of growth. | Colonies with white mycelium in evidence at different points on stem. | 2 colonies on one of 3 tubes, other 2 contaminated. Slight darkening. No evidence of pycnidia. | Pycnidia forming, mycelium spreading, aerial and submerged. | Pycnidia increased in number. Erumpent, glistening black. | Exuding spores from some pycnidia, white spore masses of pycnidia. |
| Tomato Leaf | No signs of growth. | Slight aerial mycelium, white. | No darkening of tissue. Small black specks at point of inoculation. | Increased growth; mycelium, aerial, pinkish. | Evidence of pycnidia on edge of colonies. Medium black on which colonies are growing. | Pycnidia erumpent, sparse, mycelium scanty. No signs of exudation. |
| Rice | No signs of growth. | Slight darkening of medium with evidence of mycelium on edge. | Medium black, colonies slightly increased. No signs of pycnidial formation. | Pycnidial formation contiguous, Mycelium in slight evidence, pycnidia covering entire colony. | Pycnidia erumpent, greenish yellow, spreading mycelium. | Stroma with embedded mycelium, white aerial mycelium. Exuding spores pinkish masses, long and slimy exudation. |

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| Corn-meal..... | No signs of growth. | Slight darkening of medium. Mycelium spreading, flat submerged and aerial. | Increased darkening, spreading. Signs of pycnidial formation, mycelium yellowish. | Slight evidence of pycnidia formation in black stroma. | Pycnidia formation submerged, black, dull, covered with a black mycelium. | Pycnidia clearly distinguished spore formation. No exudation. |
| Nut. Sacc. agar..... | Darkening of medium, abundant mycelium, not spreading, black grayish white mycelium on edge of colony. | Growth raised, mycelium superficial. Pycnidial formation becoming erumpent. Colonies coalescing. | Pycnidia erumpent, colonies erumpent, pycnidia covering entire colony growth except the edge which is dirty gray mycelium. | Increased growth spore formation. Very erumpent colonies. Medium darkened. | Spore exudation. No spore masses, but exudation spreading. | Grayish mycelium growing above colonies. |
| Nut. Broth..... | White mycelial colonies 6 mm. diameter. | Increased size. | No evidence of pycnidial formation. | Those colonies that were attached to side of test tube darkening, evidences of pycnidia formation. | Erumpent pycnidia, 3-7 on colony. | Exuding spores, white spore masses. |

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| Nutrient Glucose agar... | Darkening of medium. Abundant mycelium, spreading, dark except on edge of colony. | Growth raised, spreading; mycelium below surface scanty. Pycnidia formation very abundant, contiguous; colonies coalescing. | Pycnidia erumpent, black mycelium only seen on edge of colony. Entire growth made up of pycnidia. | Pycnidia erumpent, grayish black, surrounded by aerial mycelium. No increase in colony growth. | Several exuding spore masses. Mycelium grayish dirty white. | Spores exuding, grayish white masses abundant. Colonies erumpent, separate. Pycnidia contiguous. |
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| Rice..... | No signs of growth. | Slight darkening of medium with evidence of mycelium on edge. | Medium black, colonies slightly increased. No signs of pycnidial formation. | Pycnidial formation contiguous. Mycelium in slight evidence, pycnidia covering entire colony. | Pycnidia erumpent, greenish yellow, spreading mycelium. | Stroma with embedded mycelium, white aerial mycelium. Exuding spores pinkish masses, long and slimy exudation. |

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|---|---|---|---|---|---|---|---|
| Corn-meal | No signs of growth. | Slight darkening of medium. Mycelium flat submerged and aerial. | Increased darkening, spreading. Signs of pycnidial formation, mycelium yellowish. | Slight evidence of pycnidia formation in black stroma. | Pycnidia formation submerged, black, dull, covered with a black mycelium. | | Pycnidia clearly distinguished spore formation. No exudation. |
| Nut. Sacc. agar | Darkening of medium, abundant mycelium, not spreading, black grayish white mycelium on edge of colony. | Growth raised, superficial. Pycnidial formation becoming erumpent. Colonies coalescing. | Pycnidia erumpent, colonies erumpent, pycnidia covering entire colony growth except the edge which is dirty gray mycelium. | Increased growth spore formation. Very erumpent colonies. Medium darkened. | Spore exudation. No spore masses, but exudation spreading. | | Grayish mycelium growing above colonies. |
| Nut. Broth | White mycelial colonies 6 mm. diameter. | Increased size. | No evidence of pycnidial formation. | Those colonies that were attached to side of test tube darkening, evidences of pycnidia formation. | Erumpent pycnidia, 3-7 on colony. | | Exuding spores, white spore masses. |

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*Relation to Various Factors:*

Desiccation:

Exuding spore masses from a pure culture, in which spore masses had just appeared were transferred to 15 sterile cover slips in a Petri dish. A spore suspension was made from spores from the same culture and a drop of it was placed on each of 15 other sterile cover glasses. These were kept in a sterile Petri dish when dry. After varying lengths of time (see table) these slips were lifted with a sterile forceps and planted in tubes to tomato agar. The results were as follows: (+) indicating growth; (—) no growth.

TABLE 2.—EFFECT OF DESICCATION: TEST WITH SPORE MASSES AND SPORE SUSPENSION.

| Started 9-11-14. Spore Masses. | | Started 9-14-14. Spore Suspension. | |
|---|---|---|---|
| 9-11-14 | 9 P. M. + | 9-14-14 | 10 A. M. + |
| 9-12-14 | 9 P. M. + | 9-15-14 | 10 A. M. + |
| 9-14-14 | 10 A. M. + | 9-16-14 | 10 A. M. + (?) |
| 9-15-14 | 10 A. M. + | 9-17-14 | 10 A. M. + |
| 9-16-14 | 10 A. M. — | 9-18-14 | 10 A. M. — |
| 9-17-14 | 10 A. M. — | 9-19-14 | 10 A. M. — |
| 9-18-14 | 10 A. M. — | | |
| 9-19-14 | 10 A. M. — | | |

This experiment determined the resistance to drying as well as the lack of influence of the matrix upon this resistance. This experiment shows that the spore, whether in mass in the mucilaginous matrix or isolated will not resist drying more than four days. The practical application of this experiment is obvious.

Heat:

As was indicated (Page 17) an entire set of cultures on various media were incubated at 37½° forty-eight hours after inoculation at room temperature (23°). These failed to develop. Furthermore, after taking these out, fifteen days later, and allowing them to remain at room temperature for four weeks, no sign of growth was evident.

This was verified by inoculating 10 tubes of tomato agar; five were placed in 37½° C. incubator, five were retained at room temperature (about 23° C.). The tubes which were incubated at 37½° C. failed to develop, while the check tubes developed normally. The tubes were removed after 5 days and kept at room temperature but did not revive after being kept one month at 23°.

Observations in the field and of material sent in from various sources, indicated a peculiar range in the size of spots. Pycnidia were present but the actual spot formed varied greatly. Some leaves would show numerous small spots separate and distinct from one another, covering the entire leaf. On some leaflets the disease was manifested as one large spot. These variations might be dismissed as due to weather conditions. But, if it is possible under ordinary weather conditions to find spots of pin-head size, may it not be that there are some weather conditions which entirely inhibit the development of the organism? That this hypothesis is tenable has been demonstrated by experimental evidence. Inoculated tubes of cornmeal agar were allowed to develop for 48 hours and were them placed in an incubator at 29°. These did not grow further in the incubator. However, when taken out to room temperature these re-

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vived and grew normally. In this experiment two tubes were taken out each consecutive day after being placed in the incubator. When comparing all the tubes after ten days, the checks which were not put into the incubator at all, showed the greatest development, while the other tubes indicated a gradual lesser development respectively until finally the tubes taken out on the day of observation showed no development. All the tubes grew normally at room temperature maintaining a difference in growth as indicated by inhibition for 24 hours. That this is important practically, is obvious. It opens up a line of investigation which might make it possible to know what kind of weather is favorable to the fungus not from observation and hearsay but from actual laboratory tests. The lack of apparatus made it impossible to make these investigations more extensive.

However, to determine whether this would be verified on the living plant, the following experiment was performed. Two tomato plants of the same age and size were inoculated in the following manner. A spore suspension was made from a pure culture and one loop of this suspension was used for each inoculation. Twenty inoculations were made on each plant, ten on the lower surface of the leaf and ten on the upper surface. One plant was placed in the cool part of the greenhouse and the other was placed in the warmest part of the greenhouse. The first plant was placed at an average temperature of 23° C., and an average humidity of 63%. (These averages obtained from Lambrecht polymeter readings made several times a day). The second plant was placed so that the average temperature was 28° C. while the average humidity was 55%. All inoculations were successful. The plant under the cooler conditions showed difference in the lesions produced depending on whether upper or lower surfaces were inoculated. The inoculation on the upper surface gave spots 2-3 mm. in diameter, while those on the lower surfaces gave larger dead areas, 4-6 mm. With the plant at the high temperature, the spots produced by inoculations on the lower surface closely resembled those of the upper surface of plant 1, while the spots resulting from inoculations on the upper surfaces of the leaves were mere points. Eight infections of the ten were less than 1 mm. in diameter and the other two were but slightly larger.

This experiment indicates the difference in results obtained with upper and lower surface inoculations. There is also shown the effect of high temperature in inhibiting this organism while in the plant. Incidentally, this experiment indicates that a saturated atmosphere is not essential for infection to take place. The small loop of spore suspension with which the inoculation was made, disappeared almost at once when placed upon the plant. (See page 14).

Thermal Death Point of Spores:

This was determined by the method advocated by Novy (1899, p. 515) for use with bacteria. A spore suspension in 100 cc. of sterile distilled water was made using spores from a pure culture containing exuding masses 2 or 3 days old. These spores were placed in a shallow dish and then allowed to rise 5 or 8 cm. in a thin-walled capillary tube made by drawing out a sterile glass tube of about 4 mm. diameter. After the suspension had been drawn to the requisite height in the tube, the height can be determined by the slant at which the capillary tube is held, the

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end which dipped in the suspension was sealed in the flame of a microburner. Then the capillary tube was scratched with a file about half an inch beyond the liquid, broken and sealed. At one time about two dozen such spindles were prepared, and were ready for use in the experiment. The use of such small quantities of spore suspension in thin-walled tubes enables the entire mass to reach the desired temperature quickly after submersion in the water bath.

A series of water baths made of heavy cast iron were filled with water at the desired temperature. Each bath was equipped with a Bunsen burner. By varying the height of the flame and frequent observations, it was possible to maintain the temperature within the range of ½ degree. Temperatures ranging from 40° to 60° C. by gradations of 2½ degrees were used. After an exposure of ten minutes the spindles were removed and dropped into cold water. A nick was filed near one end, then the tubes were rinsed in $HgCl_2$, followed by two changes of sterile water. One tip was broken off with flamed forceps. By gently heating the unbroken tip the contents of the tube were quickly forced out into the test tubes of media. The results were as follows:

TABLE 3.—THERMAL DEATH POINT OF SPORES: TEST WITH CAPILLARY TUBES

| | |
|---|---|
| 40° + | 52½ − |
| 42½ + | 55 − |
| 45 + | 57½ − |
| 47½ + | 60 − |
| 50 + (?) | |

It may be concluded that the spores will not grow after being subjected to 52½ degrees for ten minutes. However, it is worthy of note that the number of spores which germinated and grew in tubes 40°—42½—45, were much more than that of 47½° and 50. At 50 only 6 colonies grew; at 47½, 15 colonies, while at 40—42½—45, the growth covered the entire surface of the medium and appeared exactly similar to check tubes. This resistance of certain spores raises the question whether these spores are especially heat resistant due to protoplasmic properties and whether the growing of these would give a heat resistant strain. This unfortunately could not be followed to a conclusion.

*Relation to Light:*

The Influence of Sunlight:

Three plates of cornmeal agar were poured using exuding spores from a pure culture. Two plates were exposed to the sun for three hours. After three days colonies were in evidence, with no perceptible difference in growth of exposed plates and check. Five inoculations were made on young tomato plants and exposed to the sun from 11:00 A. M. to 2:00 P. M. Five inoculations were made as checks. The inoculated plants developed typical infection, showing that for a period of at least three hours the sun had no effect upon the development of the organism. This verified the results obtained by exposing the spores in poured plates of cornmeal agar for the same length of time.

Comparison of Growth in Light and Dark:

Fourteen tubes of nutrient glucose agar were inoculated with exuding spores from a culture upon tomato agar. Seven tubes were wrapped in black paper (such as is used to cover photographic films). These

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were placed in a closed tin vessel and with the checks were placed in a dark corner of the room. After seven days, examination showed no difference excepting those in the light developed aerial mycelium. This was absent in the tubes which were covered.

It has been mentioned above (page 17) that in the experiment dealing with the growth of the organism on various media, Series 1, was placed in the greenhouse under the plants which were severally attacked by the disease. Series 2 was in the ice box. Series 4 on shelf in the laboratory window and Series 5 in laboratory but in diffused light. The results indicated that these series were indistinguishable in their development.

Relation to Oxygen:

It was mentioned also (page 17) that the experiment was carried on in triplicate, one of which was sealed. When these were examined it seemed that some tubes showed exactly similar development to the unsealed while others of the sealed tubes indicated a very scanty growth. This incongruity was explained when it was found that every "sealed" tube which appeared similar to the unsealed tubes had developed small pin holes in the sealing wax. While conclusions can hardly be drawn from such an accident it may be well to note that there was no gradation from the sealed to the unsealed; the pin holes evidently serving as efficiently for the air supply or circulation as the larger and loose cotton plugs. In the tubes which were competely sealed, slight development was evident, but no pycnidia were observed.

*Dissemination:*

The connection of the organism to some ascomycete is commonly postulated. This postulate receives support from analogy with other Septorias (Klebahn, 1908). Potebnia (1910, p. 167) has expressed the opinion that the viability of conidia of a Septoria after wintering indicates loss of the ascomycetous stage. This certainly finds no substantiation in other ascomycetous life cycles, and is not sufficient ground for elimination of the possibility of the possession of an ascus stage. Attempts were made to find this hypothetical ascomycetous form, but were unsuccessful. Affected leaves were buried at various depths in the ground, November, 1913.[7] A careful examination of this material in March, April, and May, 1914, failed to reveal an ascus form. Old, diseased stems from the previous year's crop were examined with negative results. Dried pure cultures on cornmeal were examined, revealing no perfect stage.

It is noteworthy that on the wintered stems and leaves a remarkable increase in the fungus thallus had occurred, forming a conspicuous stroma, in which the pycnidia were immersed, without however, the loss of identity of the pycnidial walls. Statements, without citation of experimental work, have been made that the fungus lives over on the trash, (Cook, 1913, Stuckey, 1915), and on greenhouse frames and sashes (Güssow, 1908). Spores from pycnidia found upon wintered over vines were put in Van Tieghem cells. Ten per cent of the spores showed active germination. It cannot be definitely affirmed that this is the only

[7]Two pieces of wire mesh (4 mm.) 12 inches square were used for this purpose. These were lined with a thin layer of cotton which was thinly covered with fine sand. Infected leaves and stems showing abundant pycnidia were placed between these wires. This was submerged in a sandy loam soil near the greenhouse at an angle of 30° with the surface of the soil, the top slightly projecting, exposing about 3 inches of the wires.

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source of infection in the field. The possibility that *Septoria lycopersici* may have some ascomycetous stage must necessarily hold in abeyance the problem of primary infection. It is very probable that part of the infection, at least, is produced by pycnidia in the old trash. The greenhouse or hot bed in which young plants are grown is an important source of infection. Seeds are planted under glass three or four weeks before they are set out in the field. Allowing five days for germination and appearance of the cotyledon there is a period of nearly three weeks in which the fungus may spread. As has been shown the period from the time of inoculation until the time of spore formation, is on the average 13 days under favorable conditions. Thus at least one secondary infection is possible after the primary infection. This infection usually shows as a series of spots about the older spot and is doubtless due to the floating out of spores from the exudations of the first formed pycnidia. Because of the comparatively long period between inoculation and spore formation, leaves are frequently found with large blotches and comparatively few pycnidia. These blotches with only a few pycnidia might be mistaken for the lesions of *Alternaria solani*.

The diseased cotyledons soon fall off and the plants are seemingly clean but a latent colony may be present on the leaves.

Numerous instances have been reported of the appearance of the disease in greenhouses in which tomatoes have never grown before. This indicates the possibility of transferrence of the fungus on the seed. Washings from tomato seeds have been centrifuged and examined repeatedly without successful results although the spore is characteristic enough to enable recognition.

It is believed, however, that the main source of infection is the trash from a previous tomato crop. It has been repeatedly demonstrated that rotation of crops diminishes the severity of Leaf-spot. If the infection came principally from the greenhouse, this rotation could hardly be so effective.

The agencies, aside from man, by which transferrence takes place are mainly water, and wind. The matrix in which the exuding spores are embedded holds the spores upon drying. These spores can be released only when soaked and in this condition they may be washed down by dew or rain. In culture pycnidia with exuding spores have retained those masses for a period of 3 months without dislodgment or germination. After this time tomato plants were inoculated with a suspension of spores and typical infection resulted. The matrix may have more or less of an inhibitory effect on the spores. A mass of spores from a newly formed exudate was placed in hanging drops but no germination resulted. Yet this retardation of germination may be due to the effects of the spores on each other, a condition strikingly illustrated in heavily seeded plates. (Stevens and Hall, 1909).

The dew washes or floats the spores about on the leaf. This causes the secondary infection which has been described. A large number of spots on the leaf usually do not develop pycnidia before the leaf dies and shrivels up. However, this dead, dried leaf which falls to the ground, if kept at all moist, has been found to develop mature pycnidia and exude spores more profusely than upon the living plant.

The important agency in dissemination is the splashing of the rain.

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The rain may carry the spores from the old, diseased leaves on the ground to the healthy leaves above, or from the diseased leaf to the leaves surrounding it. It will be recalled that in staked tomatoes the disease progresses upward beginning at the lower leaves. It is a significant fact that the spots on the lower leaves are large, indicating infection from the lower surface, while the top leaves show the characteristics of upper leaf surface inoculations.

The relation to water was demonstrated in the greenhouse. Twelve plants were grown and staked. The cotyledons of these plants were diseased. These were not removed and were allowed to fall off. The plants were watered from above twice every twenty-four hours. After two weeks all the lower leaves developed typical leaf-spot. Two weeks following, these lower leaves developed a number of secondary spots and were beginning to shrivel and dry up. The leaves above these were in about the same stage as the first leaves two weeks before. The disease spread rapidly progressing upward on the vines. When the disease had advanced about 3 feet above the soil level, 10 healthy tomato plants were transplanted between these diseased plants. Watering from above was discontinued, being replaced by careful irrigation. The plants set between the diseased plants did not develop the disease even after twenty-five days. Watering from above was now resumed and in six days the leaves of all the young plants were covered with spots.

This experiment determines the fact that the spores do not fall or float from the pycnidium as soon as produced but adhere in a mass until liberated by water. In answer to the criticism that infection did not take place because of the dryness of the leaves, it may be said that the greenhouse was always humid and furnished ideal conditions for spore germination. The experiments already reported demonstrating the independence of infection and humidity also remove any objection to this interpretation of the foregoing experiment.

The wind, as an agency in the spreading of spores, may be considered as carrying the dust which contains the spores, thus inoculating other plants. The spores germinate in a filtered soil infusion, secondary spores being produced. Viable spores have also been found in the soil about diseased plants. However, experiments performed to determine the development of the organism in the soil yielded negative results; considering that exuding spores are washed down on the soil from the diseased leaves, it is very probable that the dust must be considered as an agency for dissemination of the fungus, limited however, by the length of time the spores can stand drying and the disintegrating action of the soil.

In this connection the difference in type of infection on upper and lower leaves may be significant. The lesions on the lower leaves are of the type to indicate infection from the lower leaf surface. It is easy to conceive that the top leaves—especially when the plants are staked—are out of the zone reached by splashings of rain, but especially open to infection brought by falling dust particles.

That man is an agent in spreading disease is very evident. In cultivating the plants when they are wet, the spores are transferred to all parts of the field by the machinery coming in contact with the sticky spore masses or upon the clothing. Instances of dissemination in this manner have been observed.

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MORPHOLOGY OF CAUSAL ORGANISM.

*The Spore:*

The spores of the Septoria stage are filiform and hyaline varying from 60-120 microns in length to 2-4 microns in thickness, divided into from 3 to 9 cells. The thickness of a spore is not uniform throughout. The shape of the ends varies from pointed to globose. (Plate 8 Figure 1).

*The Mycelium:*

The mycelium of this fungus is composed of frequently septate, vacuolate threads. These threads have a diameter of from 2 microns to 3 microns. The mycelium may be said to show two types—the hyaline thin-walled type, and the dark, closely-septate, heavy-walled type. The former predominates during the vegetative stages of the growth while the latter precedes the stroma and pycnidium production. The character of these types of mycelium is brought out by figures. (Pls. 7 and 8).

*The Pycnidium:*

A number of tubes of tomato agar, cornmeal agar, and nutrient glucose agar were inoculated with a pure culture. At the end of every 24 hours after the colony was visible to the naked eye, material from these tubes was killed in Flemming's medium fixing fluid. Material was killed on successive days until exuding spore masses were in evidence.

The following schedule was followed:

| | |
|---|---|
| Flemming's medium | 24 hours |
| Washed in running tap water | 6 hours |
| 15% Alcohol | 15 minutes |
| 39% Alcohol | 30 minutes |
| 50% Alcohol | 1 hour |
| 70% Alcohol | Over night |
| 80% Alcohol | 2 hours |
| 95% Alcohol | 2 hours |
| Absolute Alcohol | 2 hours |
| ½ Cedar Oil — ½ Absolute | 1 hour |
| ¼ Cedar Oil — ¾ Absolute | 1 hour |
| Cedar Oil | 1 hour |
| Cedar Oil + paraffin | 6 hours |
| Paraffin | 2 hours |

Transferred to new paraffin (52°) and embedded after 2 hours. Some sections 5 mm. thick were made. Stains used; Flemming's Triple, Delafield's haematoxylon, Haidenhain's haematoxylon.

Continuous efforts were made to obtain results with Delafield's haematoxylon and eosin as described by Durand (1911), but with no success. Although the time which the slide was immersed in eosin was varied from 2 seconds to 5 minutes, the carbol turpentine was inadequate to remove the excess stain. Durand's method was then changed in a single particular and excellent differentiation resulted; after immersing the slide in eosin, the excess stain was washed off with absolute alcohol for a second, then was immersed in carbol turpentine and was mounted in balsam. The result was that the mycelium became a deep red and was very easily distinguished from the surrounding tissue.

As a result of a study of a culture on tomato agar after 62 to 96 hours, the following steps in pycnidium formation were observed:

The mycelium begins to anastomose and interweave, becoming browned, resembling a closely woven net, so that the fungous tissue seems to be made up of individual cells more or less rounded in shape. This small oval body increases in size while the surrounding mycelium sends out branches which augment this globose body. This enlarging continues 24-92 hours. At the end of this time, the pycnidium consists of a hollow, globose body, without an ostiole, and is 100-375 microns in diameter, with a few strands of mycelium crossing the cavity within. (Plate 5, Fig. 1).

Spore formation takes place in the same manner as described in the

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formation of the secondary spores, except that no definite elongated projection that might be considered as a well differentiated conidiophore is formed. The cells that give rise to the conidia are hyaline, resembling the peridial cells and can be traced to the brown thread from which they have arisen. Spores are produced to such an extent as to burst open the peridium at its weakest point and form an exuding spore mass sometimes twice as large as the pycnidium from which it arose. Usually that part of the peridium that is exposed is entirely broken up by the mass of spores. Plate 4, Fig. 1 illustrates this observation. In the pycnidium shown, (Plate 7, Fig. 2), the weakest point of the wall must have been submerged in the agar so that the thick part of the wall exposed to the air remained intact, while the exuding mass forced itself into the agar.

However, for complete elucidation of the method of pycnidial formation of this fungus, the development and formation of the fruiting body, must necessarily be studied in the host. Eight plants were inoculated. After three days, just as soon as the infection was visible as a small water-soaked spot, material was killed in Flemming's strong medium. Material was killed every day until the exudation of the spore masses began. The formation of pycnidia and spores was found to be identical in every particular to that described for agar cultures. The development of the pycnidial wall takes place in an exactly similar manner as in artificial media. After the "balling" up of the mycelium, the hollow case grows larger and larger, after which the spores are formed. These same sections also allowed the nature of the forces acting on the pycnidium to form the ostiole to be definitely determined. Due to the relation of the pycnidium to the surrounding tissue, the mature pycnidium finally comes to possess a more or less broad ostiole as has been pointed out by previous investigations. The steps in its origin seem to be as follows:

Soon after the pycnidium begins to form, two forces are in evidence:

1. That brought about by the enlargement of the pycnidium.
2. That brought about by the shrinking of the adjoining tissues of the leaf (a condition which can be readily seen with the unaided eye). The enlargement of the pycnidium may cause a rupture of the epidermis of the host by an upward pressure or if the fruiting body be completely embedded within the leaf tissue, there is no rupture of the epidermis.

While this fungous wall (only 3-5 cells) is pushing itself outward, the surrounding tissue is beginning to shrink due to the activity of abundant mycelium in the surrounding tissue of the latter, while the epidermis which had previously remained attached to the top of the pycnidium, begins to exert a dismembering force on all sides of the pycnidium. The great excess of this tension over the strength of the wall results in the pulling apart of the pycnidium and the formation of the so-called "ostiole." (Plate 7 shows this very clearly.) Along with this, the pressure of the spore mass no doubt, contributes to the rupture by its action at the point of greatest tension. In event, however, the pycnidium is formed within the tissue so that it does not protude above the

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surface of the leaf, or as in many cases only slightly, with the peridium remaining intact, the only factor entering into the forming a "broad ostiole" is this pressure of spores. Spores begin to form *after the peridium has developed* exactly as they are produced in culture (see above). As soon as one spore is formed another arises from the undifferentiated hymenial layer. In such a manner, spores are produced in great abundance until they completely fill this pycnidium. This mass of spores becoming larger and exerting a gradually increasing force upon the thin 3-5 celled wall, suddenly *breaks* through this pycnidial wall at the point of least resistance. This point of course is usually the part of the pycnidium nearest the upper or lower epidermis of the leaf. At no time has a definite pre-formed ostiole been observed in culture or in the leaf. In culture, the mass of spores finding the weak point in the pycnidium in the submerged part of the fruiting body, forces itself into the agar (Plate 7, Fig. 2) breaking off the lower half of the wall, the remains of which were easily determined. It will be recalled by those who have seen various Sphaeropsidales in culture that the presence of an ostiole can often be clearly distinguished before spore exudation. The entire pycnidial formation in this fungus is strikingly different from that in the regular ostiole-forming pycnidia. There is no doubt but that in this matter of presence or absence of ostiole we have a phenomenon which could readily be made of taxonomic significance. (Von Höhnell 1911).

*The Name of the Causal Organism:*

Recently Diedicke (1912) in his critical revision of the Genus *Septoria*, limited this genus to forms whose fruiting layer is enclosed in a pseudopycnidial case, which is equipped with a more or less broad opening. This work was strongly confirmed by the previously published work of Klebahn (1908) and Potebnia (1910). At this point the work of Potebnia may be cited rather fully.

In a chapter on Septoria, Phleospora, and Rhabdospora he writes, "These three genera were in general placed with the Sphaeropsidales, while in Saccardo's Sylloge (III, 577; XI, 398; XXI, 975) the position of the genus Phleospora is not determined and is placed with both the Sphaeropsidales and the Melanconiales. Those species belonging here which were studies by me show that the three genera are closely related and properly do not constitute typical Sphaeropsidales forms, because the fruiting bodies are not built as typical pycnidia. The commonly tender wall of the fruiting body consists of a network of hyphae, which lines the cavity in the leaf tissue made by the destroying activity of the fungus. Such fruiting bodies are named "Pseudopycnidia." The development on artificial substrata in the majority of species of the three genera studied is in agreement. At first the conidia-forming mycelium is produced, then there arise the "Klumpen" or "Ballen," in which Klebahn has shown for Phleospora ulmi, pycnidia (Septoria or Phleospora), and micropycnidia (Phyllosticta) are formed."

So firmly convinced is Diedicke (1912) of the potency of this distinguishing characteristic and of its taxonomic importance, that he would exclude all forms lacking this pseudopycnidium from what he considers true Septorias. This he has already done with at least two species. Diedicke would put the forms possessing Phoma-like pycnidia

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into the genus Rhabdospora. Thus in this classification the limits of Rhabdospora are circumscribed, and the old distinction emphasized by Allescher (1901). The occurrence on stems as contrasted with Septorias' occurrence on leaves, is discarded. Recent work on the Sphaeropsidales has proved the highly artificial character of this distinction. (Hedgcock, 1904, Harter, 1914).

The writer is wholly in accord with revisions of old genera when such revisions are based upon comparative morphological work with adequate materials. Adequate materials must be taken to mean fresh material from the host and from cultures rather than the fragmentary, dry material from exsiccati. Hand sections from their very meagerness and uncertainty cannot be relied upon. Without, at present, going into the merits of the case, this paper records the strong difference of morphology in *Septoria lycopersici* from that found in certain other Septorias, (Potebnia, 1910; Diedicke, 1912; and others).

If the name Septoria is to be applied to forms having *pseudopycnidia*, then a new genus must be provided for the tomato organism. At present more than 25 Septorias are being investigated in a similar manner to that described in this organism, and decision is withheld pending these studies. Accordingly the old genus name is retained.

*The Species Name:*

Spegazzini (1882)[8] first found the fungus in Argentina, South America. The Italian investigators noted a discrepancy in the description as applied to the Italian form, for Briosi and Cavara (1889) in their description of the fungus, state: "The leaves of the tomato attacked by this fungus show very numerous roundish or oblong spots, yellowish or ash colored with a thin darker margin. Perithecia appear on the upper surface. There also are found some on the lower surface of the leaf." "The perithecia are immersed in the tissue of the leaf, and have globose form, sometimes somewhat depressed, and have a parenchymatous wall, thin and olivaceous in color, and possess a broad ostiole. The spores escape in an agglutinated mass, and are of various lengths." (On the accompanying drawing the spore measurements are given as 40-120 x 2-3 microns).

"This parasite causes great injury, and attacks, according to Passerini, not only the leaves but also the stem and fruits. Furthermore, the characters which it showed in our specimens distinguished it somewhat from those indicated by Spegazzini. It does not form, as the author says, great spots which occupy almost the whole blade, nor are the perithecia scattered and mostly hyphophyllous and lenticular or hemispheric. Whence Passerini observed justly in his recent note, 'If it is not a species entirely distinct from *Septoria lycopersici* Speg., our form would at least be a form or local variety, varying from it by external characters.'"

In view of these observations, Briosi and Cavara named the leaf-spot in their locality, *Sept. lycopersici* var. *Europaea*.

[8]Spegazzini's description as given in Saccardo III, p. 535, is as follows:
Maculis magnis saepe totum folium occupantibus, sordide fuscocinerescentibus, subindeterminatis; perithecis sparsis saepius hypophyllis, lenticular-hemisphaericis, prominulis, atris, membranaceis, contextu parenchymatico, olivaceo; sporulis bacillari-cylindraceis, bacillari-subclavulatis majusculis, 70-110-3, 3-pluriseptatis, utrinque obtusiuscule attenuato-rotundatis, hyalinis. *Hab.* in foliis languidis *Solani Lycopersici* in hortis, Boca del Riachuelo Argentinae.

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Comparing the manifestations of the disease on various specimens from different localities, it was observed that the American specimens agreed closely with the description by Briosi and Cavara. Hence, it would seem that the fungus in this country answers to the description *Sept. lycopersici* var. *Europaea.*

However, observation of the fungus under a variety of conditions shows that there is not enough significance in the minor variations in size of spot, emphasized by Passerini to warrant the establishment of the variety.

As has been shown (p. 15), the size of the spot formed depends upon the number of spores with which the leaf is inoculated as well as upon which surface the leaf is inoculated. With a pure culture[9], in experiments determining the pathogenicity of the organism, a spot involving the entire leaf was frequently found. Spores from the same pure culture produced typical round spots when the spore suspension was further diluted. Spots arising from inoculation on the upper side of the leaf are much smaller and darker than those spots produced by inoculation on the under side of the leaf. In the field, the spots were very variable in size, depending upon the weather conditions. In cooler weather larger spots were produced than in hot weather. It was observed that spots formed in the secondary infection were much larger than in the primary infection. Spots with hypophyllous pycnidia were very common, both epiphyllous and hypophyllous pycnidia being usually found in the same spot. However, as a rule, the pycnidia are on the upper side of the leaf. Microscopical examination of large numbers of prepared slides showed all graduations from lenticular to globose pycnidia.

These observations are merely mentioned at this point to indicate that the activities of the fungus, affected by environmental conditions, cause manifestations sufficiently varied so that peculiarities of the lesion, which may be only functions of the intensity of attack, can hardly be sufficient basis for the formation of a new species or variety. Such a segregation to be valid would need to be based on carefully controlled conditions of the host and fungus.

The *Exsiccati* specimens accompanying the description by Briosi and Cavara were examined and could not be distinguished from specimens from American localities.

The only part of Spegazzini's description, then, which does not coincide with the manifestations as observed in this country is that the pycnidia are "most frequently" hypophyllous. Whether this is evidence that a different species or variety exists here is a question which is yet to be settled. [10]

If there is sufficient evidence that the fungus in Argentina is distinct, then it follows that we must necessarily have a name for the form found here.

The important point that must be noted is that regardless of nomenclature, the form in Europe seems identical morphologically with that

[9]In this paper all the work was done with the progeny of a single spore isolated as described on page 12.

[10]Material has been sent to Spegazzini for comparison with his type material, and with the organism as now found in Argentina.

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found in this country. This must be recognized in all discussions of experiments performed by European investigators with this fungus.

Pending a comparison of the Septoria Leaf-spot from Argentina, the specific name *"lycopersici"* is used.

## RELATION OF FUNGUS TO HOST.

*Morbid Anatomy:*

The Spore on the Host:

In order to follow the course of infection, inoculations were made on a number of plants. The epidermis was stripped off from the inoculated leaves at intervals of 6-12-24-36-48 hours. Examination showed germinating spores; at the end of 48 hours these appeared similar to spores in culture. (See p. 15). The great number of spores lengthened and grew from both ends. This was soon followed by germ tubes arising from various points on the spore. The type of infection is stomatal. (See Plate 4, Fig. 2). The mycelium may immediately enter a stoma. The spore in making its primary terminal growth in germination may enter the stoma, or if the mycelium does not come in contact with stoma immediately, the germ tube may branch and grow over the surface until it strikes a stoma. No chemotactic action leading to the finding of the stomata seemed to be manifested.

Mycelium and Tissues:

Infection may occur on both sides of the leaf. Careful study of the two types of infection were made in the various experiments when infection was desired. It was noted that when spores were placed on the upper surface of the leaflet, infection was manifested in small, narrow spots with from one to five pycnidia; the infection being more or less confined to the midrib and veins of the leaflet. Infection produced by placing the spores on the lower side of the leaflet resulted in a broad, spreading spot, and resembled for the greater part, field infection of the lower leaflets, spots forming at all points of the leaflet. This was verified by using one standard loop of spore suspension for inoculation on the upper and lower surface of leaflet, respectively.

Haustoria:

Immediately on entering the stoma, knob-like haustoria developed (See Plate 6, Fig. 2). These may be formed at once upon entering if the mycelium touches the cell wall. By enzymic action, the haustorium merely dissolves the cell wall, but does not penetrate deeply into the cell. A gradual shrinking of the pierced cells results. The mycelium grows luxuriantly through the leaf, making its greatest growth in the spongy tissue. At the end of five days the tissue is partly disintegrated and pycnidia begin to form. The mycelium commences to ball up and enlarge.

The mycelium is not confined to the disintegrating tissue. It is found in abundance through the tissue contiguous to the spot, in most cases terminating at the tracheary cells. In this outside tissue the cell relations are similar to the cells at the point of initial infection after the mycelium had grown for four days.

The period from the fifth to the thirteenth day after inoculation is characterized by the gradual shrinking and blackening of the tissues. From the half-submerged pycnidia the spores ooze out. The white spore

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masses are similar to those produced in culture. They arise in a spiral form when the opening is small. When the opening is large, they resemble those in culture. The leaves do not suffer severely from the primary infection. When two or three spots are present on a leaflet, it begins to droop and the entire leaflet turns yellow. When the spores from these spots have been washed to all parts of the leaf by the dew or rain, infection may again take place and the spots appear just as the leaf shrivels up and dries. If the spores are present in abundance the leaf will die after the first infection, if a large number of spots are formed.

This condition is usually present when the tomatoes are allowed to run over the ground. The first condition is more typical of staked tomatoes. The reduction of the photosynthetic area of the plant impoverishes it and reduces the quantity of fruit produced. The fungus attacks old and new leaves alike, but due to the incubation period of five days, a vine that was almost completely defoliated will have a small tuft of terminal leaves.

*Morbid Physiology:*

The causal organism in its attack on the leaves eventually produces defoliation and the effect of this is evident, not only in the size of the crop, but upon the character of the fruit produced. There is, however, a period when the leaves are spotted but not otherwise affected, and then follows a period in which the spots, while not enlarging, evidently influence the plant, causing a yellowing of the adjacent tissue.

Work by Galloway (1896) with a rust of pine seemed to indicate that the cause of the vast disturbance of the pine leaves followed by leaf cast was due to the excessive water loss which took place from the rifted epidermis. This conclusion is warranted from his readings. Moreover, the whole biology of the evergreen needle seems to indicate that it may be especially susceptible to a transpiration shock such as must result from a strongly perforated epidermis; but in the tomato disease the epidermis remains intact and the yellowing proceeds very slowly and the leaves do not manifest the characteristics of transpiration shock. Moreover, the recent work by Reed and his associates, Cooley (1913) and Crabill (1915), on Gymnosporangium raises important questions. These investigators did not find an acceleration of transpiration from diseased tissue.

The conclusions of Reed could not be used directly for the fungus under discussion due to the strikingly different habit on the host. Rusts are known to conserve the tissue of the host, at least until after fruiting, while with this fungus the host cells attacked were killed in a very few days and previous to fruiting body formation.

An experiment was conceived which would aim to determine the influence of the disease upon transpiration. Due to the ease with which the tomato plant is infected by this fungus, and also, because of the general structure of the tomato plant, the experiment was possible on a larger scale than has ever been used in similar investigations. Twenty-two tomato plants were grown under identical conditions in the Botanical greenhouse from seed of Earliana variety. The soil of the pots was sifted twice before being placed in these receptacles and was saturated but not water-logged. The pots were prepared as follows:

A number of stiff one-pound cheese cartons (upper diameter 10 cm.,

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bottom 7 cm.) were arranged to serve the same office as the aluminum shells used in the plant physiological laboratory. The lower third was cut off and the top portion fastened to Petri dishes with paraffin. After the paraffin had hardened, more melted paraffin was poured into the dish and the pot containing the plant was set into this paraffin before it hardened. Holes were made in the covers for the stem and corks. (Plate 3, Fig. 2). The transpiration performance of the plants was observed for a period of five days, May 2nd to 6th, inclusive, loss of weight being made up daily. At the end of this time, the number of leaves ranged from four to seven with leaflets on each leaf varying from three to seven.

Inoculations were made by placing two loopfuls of a pure culture suspension upon the lower surface of each alternate leaflet of eleven plants. The other plants were held as checks. The checks and inoculated plants were kept in a moist chamber for a period of four days to insure strong infection.[11] This was the only interval in which no weighings were taken, otherwise every twenty-four hours from May 2nd to May 20th, weighings were made and water added to bring back the original weight except that on May 12th, ten extra c. c. were added to each plant to allow for the increase in growth.

In order to determine the increase in leaf area from the time of inoculation to the time of cessation of the experiment, the following method was employed. By means of an adjustable glass plate and a tungsten light, prints were made on contrast paper (Cyko) of each leaf on every plant. These were developed and fixed in the usual manner. This was done just before inoculation, and immediately after the last reading on May 20th. By means of a planimeter, the area of the prints at various periods was obtained.

The disease was severe enough to cause the death of approximately two-thirds of the tissue of every leaflet inoculated. The tabulated data indicate the weighings and water added during the performance period when no plants were inoculated, and the last six days when 11 of the plants were infected.[12] This gives the data as to the amount of transpiration from the time that infection was visible to the first signs of general yellowing (break down) of the leaves. It is particularly necessary to bear in mind this point since this experiment was concerned only with the spots formed by the fungus and not with the secondary yellowing of the leaf which follows infection.

TABLE 4.—TRANSPIRATION OF HEALTHY AND DISEASED PLANTS: TEST BY WEIGHING PLANTS AND MEASURING LEAF SURFACE.

| | Performance record for first 5 days of experiment. | | | Performance records of checks and diseased for last 6 days. | | | |
|---|---|---|---|---|---|---|---|
| Condition of plant. | Av. area (1) in sq. meters. | Av. daily transpiration. | Transpiration per sq. m. per hour. | Av. area (2) in sq. meters. | Av. daily transpiration. | Transpiration per sq. m. per hour. | Area 2 ÷ 1. |
| Healthy thruout.. | .00862 | 13. | 62.8 | .02376 | 32.67 | 56.93 | 2.47 |
| Inoculated after first 5 days.... | .00904 | 13.1 | 60.3 | .02214 | 30.9 | 58.2 | 2.88 |

[11]At that time the independence of moisture and infection was not known.
[12]The detailed tables are given in Appendix, those given in the text being summaries.

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The above table emphasizes the similarity of the check and inoculated plants. Starting with the same average leaf surface and same transpiration per unit of area, even after more than ten days invasion by the fungus, we find the average area and average transpiration approximately the same. The difference in growth was not great.

If we examine the individual plants we are struck by the ranges in each of these relations; but careful comparisons will show that no greater variation occurs in the inoculated plants than occurs in the check plants. Moreover, both sets, before the inoculation took place, showed a similar variability. Our experiments cannot hope to avoid errors which come under this head. The number of plants possible for manipulation is so few in comparison to the number needed to eliminate error from this source, that it can hardly be hoped that experiments of this type can ever be entirely free from this factor. The following points may be made:

The method of obtaining the area eliminated a large source of error commonly present in area determination. The method of obtaining the amount transpired per plant was accurate to at least ½ gram, if not 1-10 gram. Moreover, the amount used is an average of several readings. The amount transpired per unit of area in the unit of time is very similar in each average.

Considering that in the inoculated plants, ⅔ of each alternate leaflet was diseased, we have the striking conditions of almost identical performance.

Necessarily the interpretation of this condition affects the whole experiment. We can have the following possibilities:

(1) Healthy and dead areas transpiring alike.
(2) Dead areas allowing more evaporation.
(3) Dead areas hindering water loss.

Were the first case true, the similarity of ratios is very readily accounted for, but then the death of the leaf, and the reduction of vitality must be explained on grounds other than mere water loss.

In event of the second, the yellowing of the leaves, the leaf-cast, etc., could readily be attributed to excessive water loss. Since, however, the ratios of transpiration for the leaves are almost the same, we need to postulate a repression of transpiration from the living areas.

In case the third condition were true, we need to postulate an augmented evaporation from the unaffected portion of the leaves, and attribute this to a chemical stimulation perhaps, from the by-products of the fungus.

To decide which of these conditions really existed, the following experiment was performed, with leaflets in early stages of the disease, and with leaflets which had been diseased for some time. Leaflets showing a few well defined spots were attached by the petiole to small rubber tubes. Other parts of the leaf were cut away and the cut surfaces covered with vaseline. All manipulations of attaching leaf to the rubber tube were carried on under water. The rubber tube was then attached to a potometer set up as shown in diagram. (Figure 2). In order to have conditions of humidity and temperature constant, the work was performed in an enclosed chamber (approximately 2 feet in each dimen-

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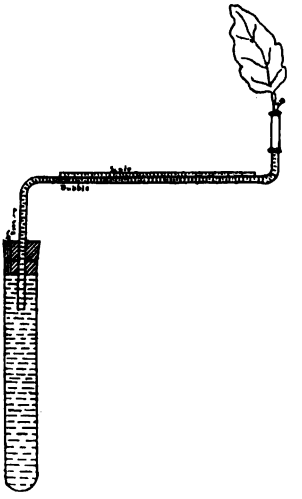

Figure 2. Diagram of potometer used to determine if diseased spots transpire.

sion). Three Lambrecht polymeters were placed in various parts of the chamber and the thermometers and hygrometers were read at each reading of water loss. The day was rather moist, and no variation occurred during the experiment. After noting the transpiration over a definite period, the diseased spots were carefully vaselined on both sides; and transpiration was noted as before. The following results were obtained:

TABLE 5.—TRANSPIRATION OF LEAFLETS IN EARLY STAGES OF DISEASE: MEASUREMENTS OF AREAS AND DISEASED SPOTS.

| Condition of leaflet. | Area of 1 surface. | Number of spots on leaflet. | Diseased area 1 surface. | Per cent of leaflet diseased. |
|---|---|---|---|---|
| 1. Leaflets green; spots pliable | 1.6 sq. in. (by planimeter) | 9 | .054 sq. in. | 3.3% |
| 2. Leaflets green; spots pliable | 2.05 sq. in. | 5 | .03 sq. in. | 1.4% |
| 3. Leaflets green; spots pliable | 2.4 sq. in. | 32 | .192 sq. in. | 10. % |
| 4. Leaflets green; spots pliable | 2.3 sq. in. | 7 | .084 sq. in. | 3.6% |
| Average | | | | 4.8% |

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TABLE 6.—TRANSPIRATION OF LEAFLETS IN EARLY STAGES OF DISEASE: PERFORMANCE OF POTOMETERS.

| Potometer | Movement of bubble before diseased spots were vaselined. | | Movement of bubble after diseased spots were vaselined. | | Rate (a). | Rate (b). | Ratio of water of movement b ÷ a. |
|---|---|---|---|---|---|---|---|
| | Time. | Spaces. | Time. | Spaces. | Before (spaces per min.) | After (spaces per min.) | |
| 1 | 33 min. | 9 | 123 min. | 27 | .27 | .22 | .81 |
| 2 | 83 min. | 12 | 74 min. | 41 | .749 | .51 | .70 |
| 3 | 40 min. | 22 | 103 min. | 29.5 | .55 | .19 | .35 |
| 4 | 41 min. | 22.5 | 114 min. | 31 | .54 | .27 | .50 |
| Average | | | | | | | .59 |

TABLE 7.—TRANSPIRATION OF LEAFLETS IN LATER STAGE OF DISEASE: MEASUREMENT OF AREAS AND DISEASED SPOTS.

| Potometer. | Condition of leaflet. | Area of 1 surface. | Number of spots on leaflet. | Diseased area (1 surface). | Per cent of leaflet diseased. |
|---|---|---|---|---|---|
| 5 | Leaflet yellowed; spots dry | 1.4 sq. in. (by planimeter). | 16 | .192 | 13% |
| 6 | Leaflet yellowed; spots dry | .5 sq. in. | 11 | .08 | 16% |

TABLE 8.—TRANSPIRATION OF LEAFLETS IN LATER STAGES OF DISEASE: PERFORMANCE OF POTOMETERS.

| Potometer. | Movement of bubble before diseased spots were vaselined. | | Movement of bubble after diseased spots were vaselined. | | Rate before (a) (spaces per min.) | Rate after (b) (spaces per min.) | Ratio of rates of movement (b ÷ a). |
|---|---|---|---|---|---|---|---|
| | Time. | Spaces. | Time. | Spaces. | | | |
| 5 | 42 min. | 2.5 | 92 min. | 5.5 | .06 | .06 | 1. |
| 6 | 39 min. | 7 | 88 min. | 13.5 | .18 | .15 | .83 |

In the cases where the leaflets were green and spots pliable, (Tables 5 and 6), the decrease in rate of transpiration after the vaseline was applied is far greater than the mere decrease in transpiring surface would warrant. Although the spots were on an average only 4.8 per cent of the total leaf surface, the transpiration was cut down nearly one-half (.59) by vaselining the spots. This indicates that in early cases of attack, the diseased spots evaporate more than the healthy portions.

In the potometers with the yellowed leaves, (Tables 7 and 8), there

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was little or no transpiration from the diseased spots, indicating that with complete desiccation and shrinkage, the spots are cut off from the water supply.

Of the three possibilities outlined on page 34, the experiment points to the second case where the diseased areas transpire more and the healthy portions of the leaflets less, but the writer is fully aware of the meagreness of his data.

## IMMUNITY PHENOMENA.

*Cross Inoculations:*

The following plants related to the tomato were inoculated by placing a loopful of spore suspension from a pure culture on various leaflets.[15]

Solanum quinescens
Capsicum frutescens
Nicotiana tabacum (tobacco)
Solanum tuberosum (potato)
Solanum villosum

Within five days the potatoes showed definite small black spots on all the inoculated leaflets, while the check leaflets showed no infection. None of the other plants showed any spots.

The experiment was repeated with the same results. Various attempts to find pycnidia in the infected areas of the inoculated potato leaves have failed in these preliminary experiments. This is a most interesting result inasmuch as no Septoria has been described upon potato (Saccardo). It is also hard to explain the absence of such a record in view of the frequent association of tomatoes and potatoes in the field, unless the failure to produce pycnidia is a uniform condition. More extensive experiments are planned. At present, it is important to note that these spots were obtained by merely applying the spores, not injuring the tissue in any way. The importance of further investigation upon this point is obvious.

Susceptibility of Varieties:

The following varieties were obtained from D. M. Ferry & Co., Detroit, Mich., Vaughan Seed Co., Chicago, Peter Henderson & Co., New York, to whom thanks are due:

*D. M. Ferry & Co.*

| | | |
|---|---|---|
| Perfection | White Apple | June Pink |
| Buckeye State | Early Detroit | Golden Queen |
| Ponderosa | Early Michigan | Dwarf Champion |
| Peach | Stone | Chalk's Early Jewel |
| Magnus | Acme | Coreless |
| Beauty | Matchless | Earliana |

[15]The leaflets not inoculated acted as checks.

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*Peter Henderson & Co.*

| | | |
|---|---|---|
| Perfection | Chalk's Early Jewel | Stone |
| Tenderloin | Beauty | Livingstone's Globe |
| June Pink | Early Freedom | Ponderosa |
| Crimson Cushion | Dwarf Champion | |

*Vaughan Seed Co.*

| | | |
|---|---|---|
| Red Plum | Sutton's Best of All | Golden Queen |
| Bonny Best | Enormous | Yellow Peach |
| Trophy | Lorillard | Vaughan's Model |
| Stone | Yellow Plum | Ground Cherry or Husk |
| Livingstone's Beauty | Fall Champion | Livingstone's Globe |
| Ponderosa | Sterling Castle | Cream City |
| Crimson Cushion | Pear-shaped Yellow | Red Peach |
| Freedom | Atlantic Prize | Chalk's Jewel |
| Dwarf Stone | Red Cherry | Early Michigan |
| Matchless | Frogmore Select | Imperial |
| Magnus | Honor Bright | Coreless |
| Acme | Comet | Buckeye State |
| Earliest of All | Sunrise | June Pink |
| Perfection | Hubert's Marvel | Early Detroit |
| Livingstone's Favorite | Hummer | Dwarf Champion |
| Pear-shaped Red | Red Currant | Dwarf Aristocrat |

Ten plants of each of the varieties listed were grown. Five were inoculated after the method previously given, five were left as checks. Every inoculated plant developed the disease except the Currant tomato and the Ground Cherry. The Currant tomato, however, is by most systematists classed as a different species, and this relation to a pathogenic fungus is believed by many to be a confirmatory test of a *specific* entity. The Ground Cherry belongs to another genus (Physalis). This experiment was not intended to determine the relative effect of the disease on the plant in the field. There are a number of factors which these results do not recognize; the ability of the plant to form new leaves, the mechanical structure of the leaves, etc. This experiment, however, does point out that in the common varieties of the tomato, with this particular organism, there is no variety strikingly immune or susceptible to this disease.

It is believed in various sections of the country that the Globe is a resistant variety—this statement being often seen in horticultural papers. G. Köck (1907) classes certain varieties as resistant, less resistant, and strongly susceptible, as follows:

Resistant—Wonder of the Market, Up-to-date, Mikado, King Humbert;

Less Resistant—Magnum Bonum, Prelude, Ponderosa, Pres. Garfield and Alice Roosevelt;

Especially Susceptible—Trophy, Ficarazzi.

The varieties tested appeared neither more or less strongly affected than any other. From investigations carried on, it is found that there is no evidence of a distinction, even in the size of the spots formed among these varieties, provided the spore suspension is applied to the

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lower part of the leaf with relatively the same number of spores in each inoculation. G. Köck does not mention his method in arriving at his conclusions. This, of course, precludes the possibility of comparison of results. Judging from his article he relied merely on field appearances. It is interesting to contrast the following observations by J. B. S. Norton (1914): "Practically all the varieties grown in America and Europe have been tried here the past two years, and all showed about the same amount of Septoria Blight on the foliage. Some varieties are, however, more vigorous growers and continually keep ahead of the blight by the production of new foliage."

Here as in all work on resistance and immunity in reference to plant disease, the whole matter of resistance and susceptibility is obscured by disease *Tolerance and Escape.* (Orton, 1908; Freeman, 1911). We might add to this the ability to repair or replace damaged tissue. In view of the total lack of any superiority of any one variety in the experiments reported, the writer feels that the explanation of Norton is correct and the rapidity of growth of some varieties (as contrasted with the slowness of the dwarfs) is responsible for the apparent cases of resistance to disease of certain varieties of the tomato, *Lycopersicon lycopersicon.*

## RECOMMENDATIONS FOR CONTROL MEASURES.

Before control measures can be considered, we must recognize the following observations that have been dealt with above:

1. The sources of infection are at least two: the greenhouse or the hotbed and the old trash in the field.
2. Infection results from inoculation upon the upper and lower surfaces of the leaf.
3. The period from the time of inoculation to spore exudation is about 13 days.
4. Moisture is the primary agent in dissemination of the disease.
5. The exudate of spores is in the form of a mucilaginous *mass.* The spores are always transferred by some external agency.
6. It has been shown that the mycelium will not grow at 37½° F., (98° C.) and will not revive after ten days at this temperature. Since this temperature is frequently reached during the summer months, this must be taken into consideration as a natural means of checking the disease.

The most important control measures for this disease are prophylactic. Clean seedlings in clean soil, if reasonably isolated remain practically free from the disease.

In order to be sure that the seedlings do not become diseased at the start, clean soil should be used in the greenhouses devoted to seedling production. The soil should be fresh or sterilized. The seedlings should be sprayed as soon as their height above ground makes it practicable, and again before being transplanted to the field. For this a weak Bordeaux mixture (2-2-50) is advised.

Since it has been determined that wintered-over, diseased vines possess spores which are viable, the old trash must be destroyed as far as possible. Since, however, this is not practical except in greenhouses and

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gardens, rotation is strongly urged. While there is no experimental evidence to demonstrate the value of rotation as a means of control, numerous instances have been noted in which rotation has been successful in controlling the disease.

After transplanting to the field, spray with 4-4-50 Bordeaux mixture every 10 days. As has been shown, the period from time of inoculation to spore exudation is at least 13 days. Allowing this leeway for differences in period of infection, it would seem that a spray so applied would give the necessary protection.

The greatest part of and the strongest infection results from inoculation on the lower surface of the leaf. Therefore, all these precautions are less effective if the plants are allowed to run at will over the ground. The spraying of the under side of the leaf is not accomplished unless the application is thorough. Failures to control the disease by spraying are doubtless due to lack of thoroughness and timeliness.

Moisture acts as a mechanical factor in disseminating the disease in two ways. (1). The dew carries the spores from the mucilaginous mass to all parts of the leaflet to form secondary infection. (2). The rain by splashing, carries the spores from the ground below to the leaves above and in a similar manner carries the spores from the diseased leaves on the ground to the healthy leaves above.

The mucilaginous matrix holds the spores until they are released by contact with some object. When the plants are dry, the spores do not float in the air or fall from the leaf but stay embedded in this matrix, which becomes hard and strongly cohesive.

Accordingly the plants should not be "worked" when wet. Growers have reported cases where cultivation began at a small infected patch and the disease was carried over the entire field, and that in less than three weeks the entire field was spotted. This is now readily explained. In greenhouse practice, irrigation should replace the ordinary use of the hose.

Spraying with 4-4-50 Bordeaux mixture in the fields where tomatoes are staked should be extremely successful. In this state spraying will not pay unless the spray reaches the lower surface of the leaves. A sprayer such as is used for potatoes, with two side nozzles set to shoot upward and if practical, with one central nozzle to spray downward for each row will, under high pressure, be most efficient in Michigan fields.

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## SUMMARY.

This bulletin gives the results of experiments with the Leaf-Spot disease of tomato and recommendations for its control. After a discussion of the previous work on the disease, the disease is discussed under topics:—Name, Economic Importance, and Distribution. The disease manifests itself by forming lesions on leaves, stems, calyx, and fruit.

Since previous work for the most part inferred the connection of the associated fungus and the disease, or at least was not entirely conclusive, formal proof of parasitism was undertaken. This work proved that the organism, *Septoria lycopersici* Speg., causes the disease. Studies of infection phenomena were given under the topics:—Period of Incubation, Subsequent Development, and The Relation of Infection to Moisture.

The physiological and ecological relations of the causal organism were studied under the topics:—Germination, Growth on Media, Relation to Dessication, Heat, Light, Oxygen, and Dissemination.

Morphology of the causal organism indicated that the pycnidium is a closed ball with a wall similar to that in the genus Phoma. The spores are long and needle-shaped bodies with pointed or rounded ends, usually with several septa. The mycelium is of two sorts. The morphology of this organism shows a striking difference from that found in the members of the genus Septoria studied by Potebnia, Diedicke and Klebahn. There is no proof available to show that the organism in the United States is different from that in Argentine, hence the specific name, *lycopersici,* is retained.

In considering the relation of the fungus to the host, it was found that the type of infection is stomatal. The mycelium is intercellular and possesses haustoria.

An experiment to determine the morbid physiology of the plants infected by Septoria indicated that healthy and diseased plants transpired nearly alike per unit of area. There was, however, an indication that the diseased spots transpire more than the healthy portions of the affected leaves, and that the transpiration of these healthy portions is repressed below normal. The fungus was found to infect the potato when the latter is artificially inoculated. No fruiting bodies were produced in the disease spots. No variety of tomato was found especially susceptible or immune although more than fifty were tried. Control measures, chiefly prophylactic, are recommended.

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## APPENDIX.

### Media Used in Cultural Work with the Fungus.

*Cornmeal Agar (Shear):*

Four teaspoonfuls of yellow cornmeal were added to a liter of distilled water. Digested in water bath below 60° for one hour, 1.3% agar was added and boiled for 45 minutes; water lost added; albumen of two eggs added for clearing. Filtered through absorbent cotton and tubed. Autoclaved 15 minutes 110°

*Prune Juice Agar:*

One hundred twenty gms. of dry prune flesh. Boiled in one liter of distilled water in steamer for two hours. Filtered through cheesecloth and 12 gms. of agar added. Boiled two hours in steamer until completely dissolved. Cleared with albumen of two eggs. Filtered through absorbent cotton. Autoclaved 15 minutes 110°.

*Tomato Leaf Agar:*

Green tomato leaves were pressed and 60 cc. of juice was boiled in 500 cc. of water and then 12 grams agar flour was added to juice, boiled 45 minutes and cleared with albumen of two eggs. Filtered through cotton. Autoclaved 10 min. 110°.

*Nutrient Glucose Agar:*

Digested 20 gms. of agar in 500 cc. of water. Dissolved in 500 cc. of water 40 gms. of glucose, 3 gms. of beef extract, 3 gms. of salt, 20 gms. of peptone. Poured into agar and steamed for 45 minutes. Cleared with albumen of two eggs. Filtered through absorbent cotton. Autoclaved 10 minutes at 110°.

*Nutrient Saccharose Agar:*

Digested 30 gms. of agar in 500 cc. of water. Dissolved in 500 cc. of water 40 gms. of saccharose, 3 gms. beef extract, 3 gms, salt, 20 gms. peptone. Poured into agar and steamed for 45 minutes. Cleared with albumen of two eggs. Filtered through absorbent cotton. Autoclaved 10 minutes at 110°.

*Nutrient Broth:*

Dissolved 3 gms. of Leibig's beef extract in a liter of water to which was added 10 gms. peptone, 5 gms. of common salt; neutralized with normal NaOH to 1° Fuller's Scale. Autoclaved 10 minutes at 110°.

*Bean Pods:*

Canned bean pods placed with ½ inch distilled water in test tubes. Autoclaved at 110° fifteen minutes.

*Potato Plugs:*

Potato plugs made with cork borer. Soaked in running water 24 hours. Placed in tubes in bottom of which a small wad of cotton soaked

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in distilled water was placed. Steamed three consecutive days for 15 minutes.

*Tomato Leaves:*

Young leaves were cut from growing vines. These were placed in test tubes with 2 cc. distilled water. Autoclaved at 110° for 5 minutes.

*Tomato Stems:*

Stems were prepared in the same manner as the leaves.

*Cornmeal:*

A teaspoonful of cornmeal in large test tube to which was added four times volume of distilled water. Steamed 3 consecutive days for 15 minutes.

*Rice:*

Rice was prepared in the same manner as cornmeal.

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TABLE 9.—TRANSPIRATION RECORDS OF HEALTHY PLANTS IN EXPERIMENT REPORTED ON PAGE 33: PLANIMETER READINGS MADE IN SQUARE INCHES. Healthy throughout.

| Plant. | Water loss in grams. May. 2. | 3. | 4. | 5. | 6. | Total loss in 120 hrs. | Average daily transpiration. | Area in sq. in. | Area in sq. m. | Transpiration per sq. m. per hour. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10. | 9. | 8.3 | 3. | 6. | 36.5 | 7.3 | 13.95 | .005510 | 55.17 |
| 2 | 26.5 | 27.5 | 23. | 9. | 13. | 32.27 | 19.8 | 32.27 | .01277 | 64.68 |
| 3 | 16. | 19. | 17 5 | 7.5 | 12. | 72. | 14.4 | 21.60 | .00858 | 69.8 |
| 4 | 9. | 9.5 | 10. | 4. | 6. | 38.5 | 7.7 | 15.38 | .00607 | 52.82 |
| 5 | 17. | 19. | 17. | 7.5 | 13. | 73.5 | 14.7 | 27.98 | .01104 | 55.42 |
| 6 | 14. | 16. | 13. | 4. | 7.5 | 54.5 | 10.9 | 14.72 | .00582 | 77.95 |
| 7 | 14. | 13 5 | 11. | 4.5 | 11. | 54. | 10.8 | 21.27 | .008405 | 53.5 |
| 8 | 19. | 16.5 | 13.5 | 2.5 | 12.5 | 64. | 12.8 | 21.19 | .00837 | 63.7 |
| 13 | 21. | 21. | 20. | 8. | 15. | 85. | 17. | 30.22 | .01195 | 59.25 |
| 14 | 33.5 | 30.5 | 24.5 | 12. | 20.5 | 121. | 24.2 | 37.67 | .01490 | 67.8 |
| 16 | 18. | 17.5 | 14. | 7.5 | 12.5 | 68 5 | 13.7 | 23.67 | .008365 | 68.25 |
| Average | | | | | | | 13. | 21.81 | .00862 | 62.8 |

| Plant. | Water loss in grams. May. 15. | 16. | 17. | 18. | 19. | 20. | Total loss in 144 hrs. | Average daily transpiration. | Area in sq. in. | Area in m. | Average transpiration per sq. m. per hr. | Gain in area in sq. m. | Area (2) + by Area (1). |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 22. | 20.5 | 28.5 | 26. | 28. | 28.5 | 153 5 | 25.58 | 52.04 | .02058 | 37.24 | .01507 | 3.7 |
| 2 | 43. | 39. | 47. | 43. | 45. | 42.5 | 259.5 | 43 25 | 66.51 | .02625 | 68.52 | .01348 | 2. |
| 3 | 43.5 | 36.5 | 48.5 | 44. | 46. | 43.5 | 262. | 43.6 | 67 69 | .02665 | 69.65 | .01807 | 1.9 |
| 4 | 31.5 | 26.5 | 34.5 | 36.5 | 43. | 43. | 215. | 35.83 | 60.29 | 02380 | 62.7 | .01773 | 2.9 |
| 5 | 35.5 | 28.5 | 37. | 36.5 | 38. | 34.5 | 210 | 35 | 63.77 | .02520 | 57.8 | .01416 | 2.2 |
| 6 | 22. | 19. | 26. | 21.5 | 24.5 | 21.5 | 134.5 | 22.42 | 33.55 | .01321 | 71.04 | .00743 | 2.2 |
| 7 | 30. | 29.5 | 33. | 33.5 | 33.5 | 31 5 | 191 | 31.83 | 67.51 | .02664 | 49.75 | .01823 | 3.1 |
| 8 | 34.5 | 20.5 | 35. | 30.5 | 37. | 32.5 | 190. | 31.65 | 48 97 | 01935 | 63.15 | .01098 | 2.3 |
| 13 | 18.5 | 20.5 | 23. | 22. | 21. | 21. | 126. | 21 | 61.12 | .02418 | 36 22 | .01323 | 2.5 |
| 14 | 29.5 | 34.5 | 42. | 32.5 | 35. | 32.5 | 206. | 34.33 | 79 92 | .03128 | 45 7 | .02638 | 2.3 |
| 16 | 32. | 24.5 | 39.5 | 38. | 39. | 36. | 309. | 34.83 | 61 32 | .02420 | 59.99 | .01584 | 2.6 |
| Average | | | | | | | | 32 67 | 60 24 | .02376 | 56.93 | .01546 | 2 47 |

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TABLE 10.—TRANSPIRATION RECORDS OF INOCULATED PLANTS IN EXPERIMENT REPORTED ON PAGE 33: PLANIMETER READINGS MADE IN SQUARE INCHES.
Inoculated on May 7.

| Plant. | Water loss in grams. May. 2. | 3. | 4. | 5. | 6. | Total loss in 120 hrs. | Average daily transpiration. | Area in sq. in. | Area in sq. m. | Transpiration per sq. m. per hour. |
|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 14.5 | 16 | 15 | 6. | 11.5 | 63. | 12.6 | 28.61 | .01131 | 46.4 |
| 10 | 17.5 | 16 | 14.5 | 5.5 | 12.5 | 66. | 13.2 | 23.64 | .00934 | 58.85 |
| 11 | 16. | 18.5 | 16. | 6.5 | 12. | 69. | 13.8 | 24.16 | .00955 | 60.2 |
| 12 | 9.5 | 9.5 | 9. | 3.5 | 7. | 38.5 | 7.7 | 12.53 | .004958 | 64.73 |
| 15 | 28. | 26.5 | 20. | 11.5 | 18.5 | 104.5 | 20.9 | 36.37 | .01396 | 62.4 |
| 17 | 19.5 | 20.5 | 17. | 8. | 13.5 | 78.5 | 15.7 | 23.49 | .00928 | 70.4 |
| 18 | 11.5 | 11. | 9.5 | 3.5 | 6. | 41.5 | 8.3 | 9.56 | .00377 | 91.6 |
| 19 | 20. | 20. | 18. | 10.5 | 14.5 | 83. | 16.6 | 27.25 | .01078 | 64.18 |
| 20 | 11. | 13.5 | 11.5 | 4. | 7. | 47. | 9.4 | 16.78 | .00666 | 58.78 |
| 21 | 20.5 | 20.5 | 20. | 20. | 16.5 | 87.5 | 17.5 | 29.84 | .0118 | 61.75 |
| 22 | 9. | 9.5 | 8.5 | 3. | 6.5 | 36.5 | 7.3 | 11.65 | .0046 | 66.2 |
| Average | | | | | | 22.88 | 13.1 | 22.88 | .00904 | 60.3 |

| Plant. | Water loss in grams. May. 15. | 16. | 17. | 18. | 19. | 20. | Total loss in 144 hrs. | Average daily transpiration. | Area in sq. in. | Area in m. | Average transpiration per sq. m. per hr. | Gain in area in sq. m. | Area (2) ÷ by Area (1). |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 25. | 23. | 31. | 31. | 34. | 31. | 115 | 29.2 | 65.54 | 02552 | 45.75 | .01421 | 2.2 |
| 10 | 28. | 25.5 | 38.5 | 38.5 | 41 | 45.5 | 227 | 37.9 | 65.59 | .02593 | 61.02 | .01659 | 2.7 |
| 11 | 41.5 | 37.5 | 46.5 | 43. | 46. | 42. | 256.5 | 42.7 | 71.24 | 02815 | 63.25 | .01860 | 2.9 |
| 12 | 26.5 | 21.5 | 29. | 29. | 35.5 | 37. | 178.5 | 29.8 | 55.30 | 02816 | 56.85 | .01788 | 4.4 |
| 15 | 32.5 | 34 | 49.5 | 38.5 | 43. | 40. | 237.5 | 39.6 | 97.01 | .03839 | 43.00 | .02438 | 2.6 |
| 17 | 40. | 27. | 42.5 | 39. | 42.5 | 49. | 231 | 38.5 | 70.10 | .02808 | 57.15 | .01880 | 2.9 |
| 18 | 14. | 9. | 15. | 19.5 | 14. | 12. | 84. | 14. | 15.88 | .00627 | 93.00 | .00250 | 1.7 |
| 19 | 25.5 | 23.5 | 29.5 | 29.5 | 29.5 | 27. | 162.5 | 27.1 | 69.31 | 02738 | 41.3 | .01660 | 2.5 |
| 20 | 30. | 23. | 29.5 | 30.5 | 35. | 33.5 | 181.5 | 30.2 | 59.33 | 02344 | 53.52 | .01678 | 3.5 |
| 21 | 36.5 | 24.5 | 31 | 29. | 29. | 29. | 170. | 28.3 | 59.70 | .0236 | 50.00 | .01180 | 2.5 |
| 22 | 21.5 | 10. | 28.5 | 23. | 27.5 | 24. | 137.5 | 22.9 | 41.01 | 01622 | 58.85 | 01162 | 3.5 |
| Average | | | | | | | | 30.9 | 60.82 | .02214 | 58.2 | 01310 | 2.88 |

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## DESCRIPTION OF PLATES.

Plate 1.
Diseased plant showing killing of lower leaves.

Plate 2.
Fig. 1. The disease as found in the field.
Fig. 2. Diseased spots X 5.

Plate 3.
Fig. 1. Van Tieghem cells with distilled water and nutrient glucose agar.
Fig. 2. Plants used in transpiration experiment. The pots are inside of cheese cartons which are cemented to Petri dishes with paraffin.

Plate 4.
Fig. 1. Pycnidium in the leaf, showing spores pushing out, thus making the ostiole. X 250.
Fig. 2. Test tube cultures on tomato agar and nutrient glucose agar showing spore exudation.
Fig. 3. Section of sub-stomatal chamber of leaf showing entrance of mycelium. X 1,000.

Plate 5.
Fig. 1. Pycnidum before arisal of spores showing mycelial strands running across the chamber. X 750.
Fig. 2. Magnified camera drawing showing nature of young pycnidial wall. X 750.

Plate 6.
Fig. 1. Mycelium in hanging drop culture showing arisal of secondary spores, and heavy-walled mycelium.
Fig. 2. Mycelium between the cells of the host, sending blunt, tubular haustoria into the cells. X 1,000.

Plate 7.
Fig. 1. Pycnidium on a tomato leaf, showing relation of spores and adjacent tissue to ostiole formation. X 800.
Fig. 2. Pycnidium from test tube culture showing spores masses pushing into agar. X 300.

Plate 8.
Fig. 1. Spore showing globose ends.
Fig. 2. Germinating spores producing secondary spores.
Fig. 3. Secondary spore germinating.
Fig. 4. Mycelium producing secondary spores (corn meal agar).
Fig. 5. Mycelium branching, no secondary spores (nutrient glucose agar).

Plate 9.
Fig. 1. Germinating spore (tomato agar).
Fig. 2, 4 and 5. Stages in colony formation.
Fig. 3. Spore germinating by elongation of both ends, (nutrient broth).
Fig. 6. Mycelium with secondary spores, and heavy brown threads (corn meal agar).
Fig. 7. Mycelium (nutrient glucose agar).
Fig. 8. Pycnidium formation (corn meal agar).

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**PLATE 1.**

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PLATE 2.

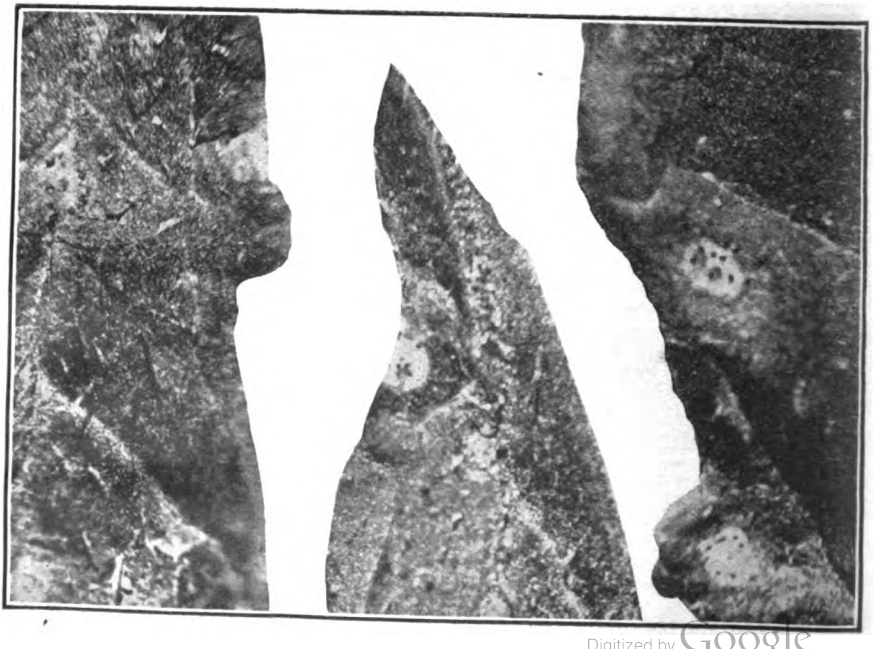

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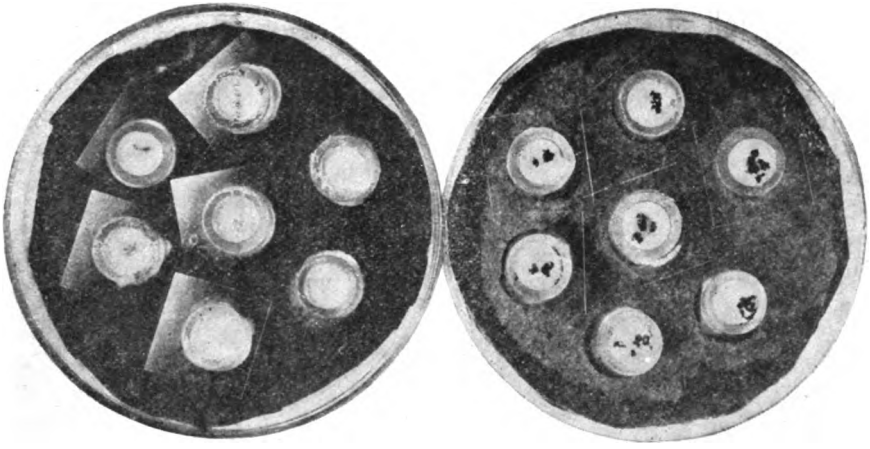
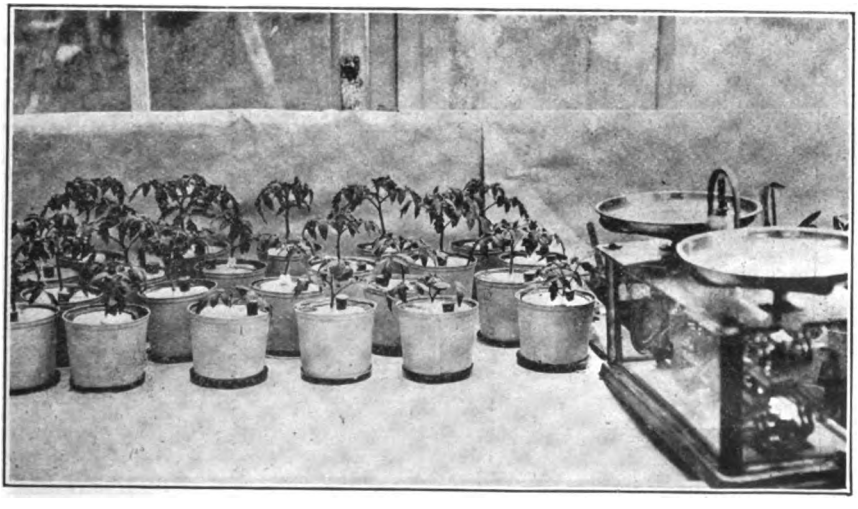
PLATE 8.





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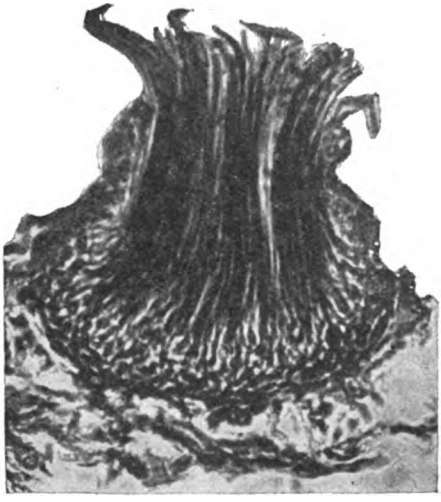

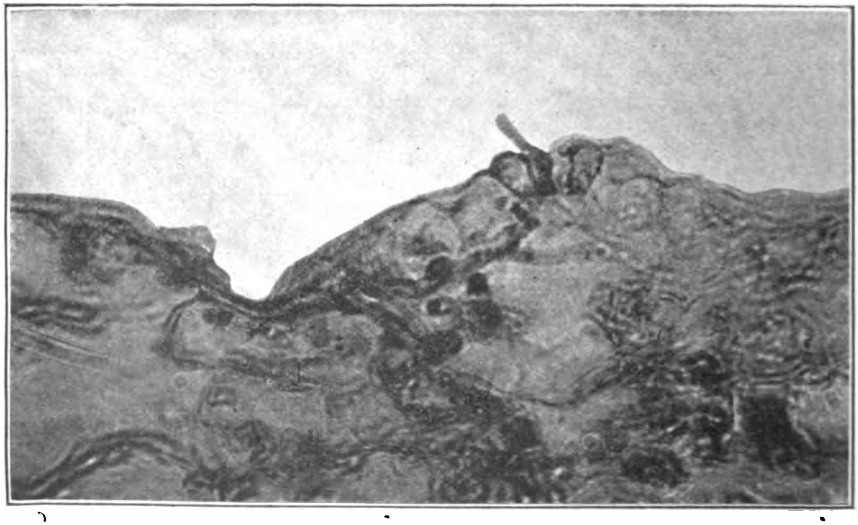

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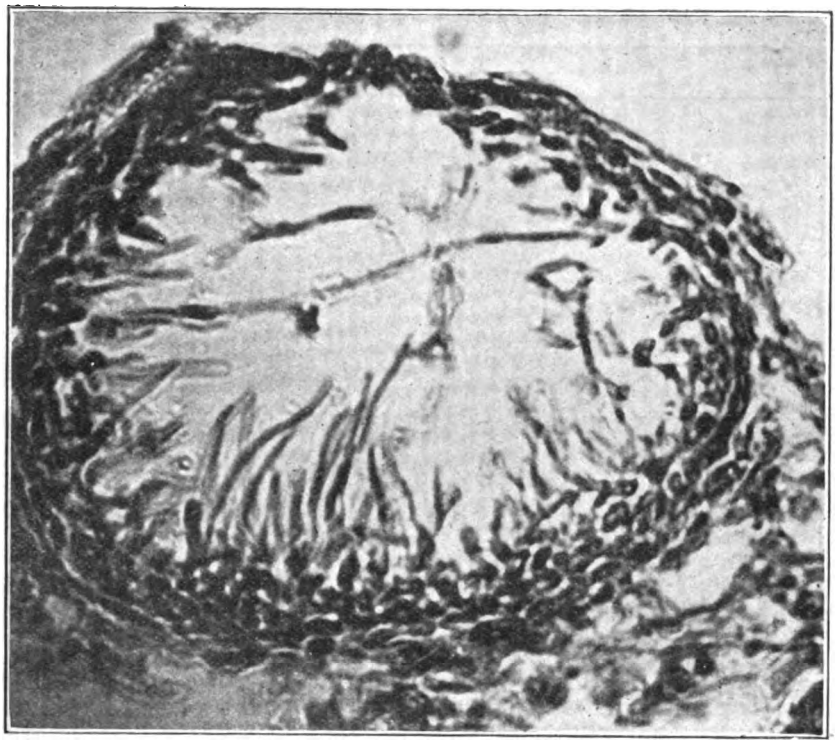

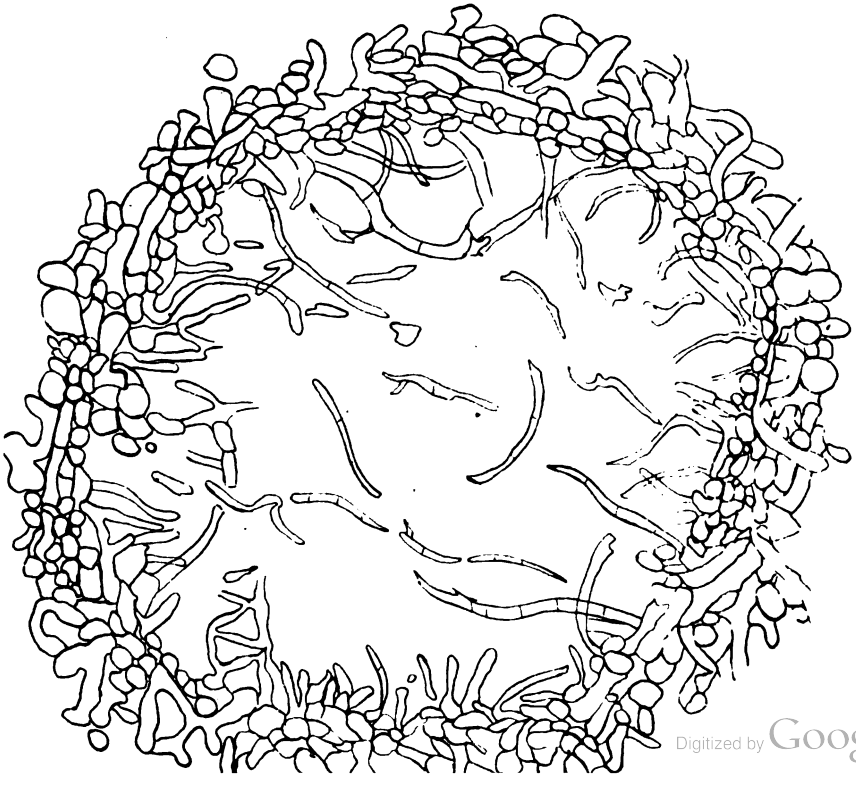

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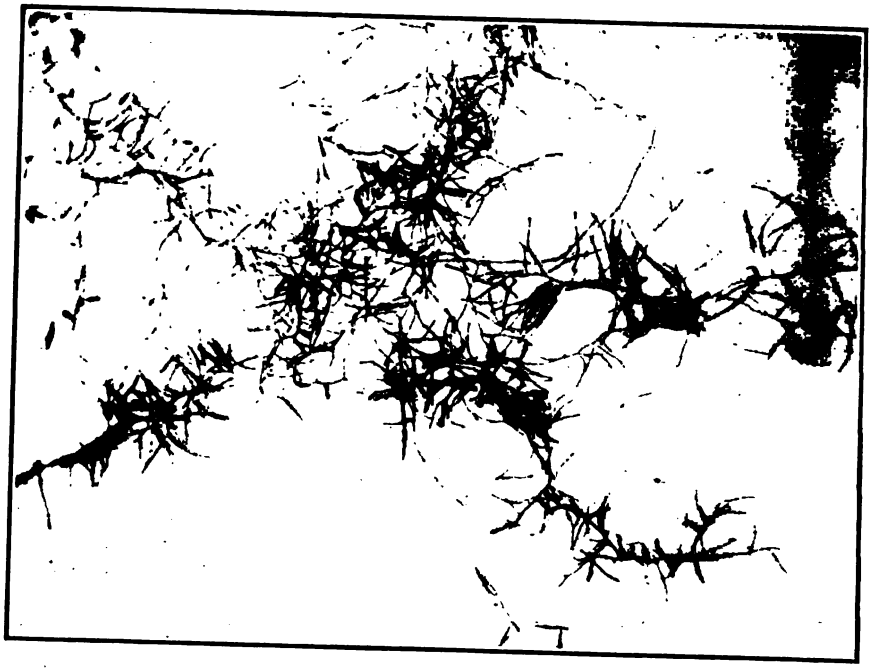

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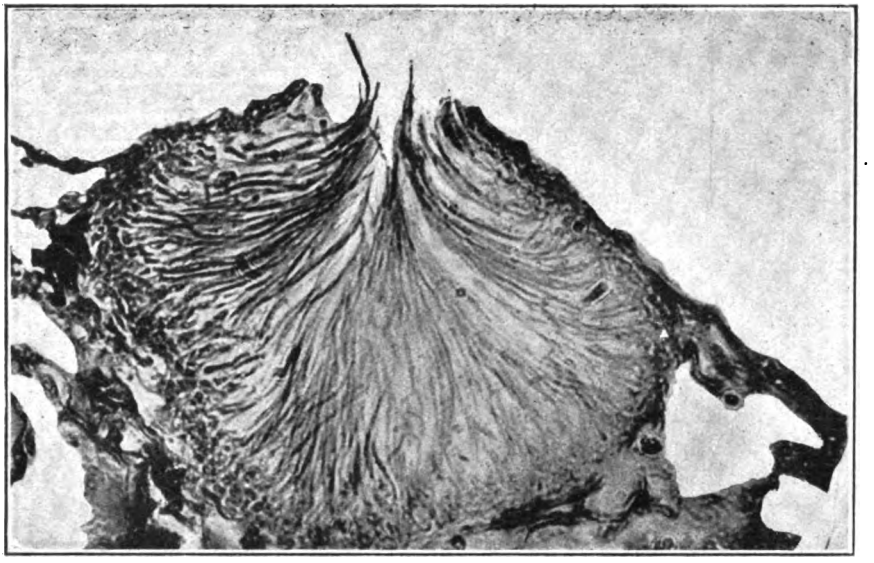

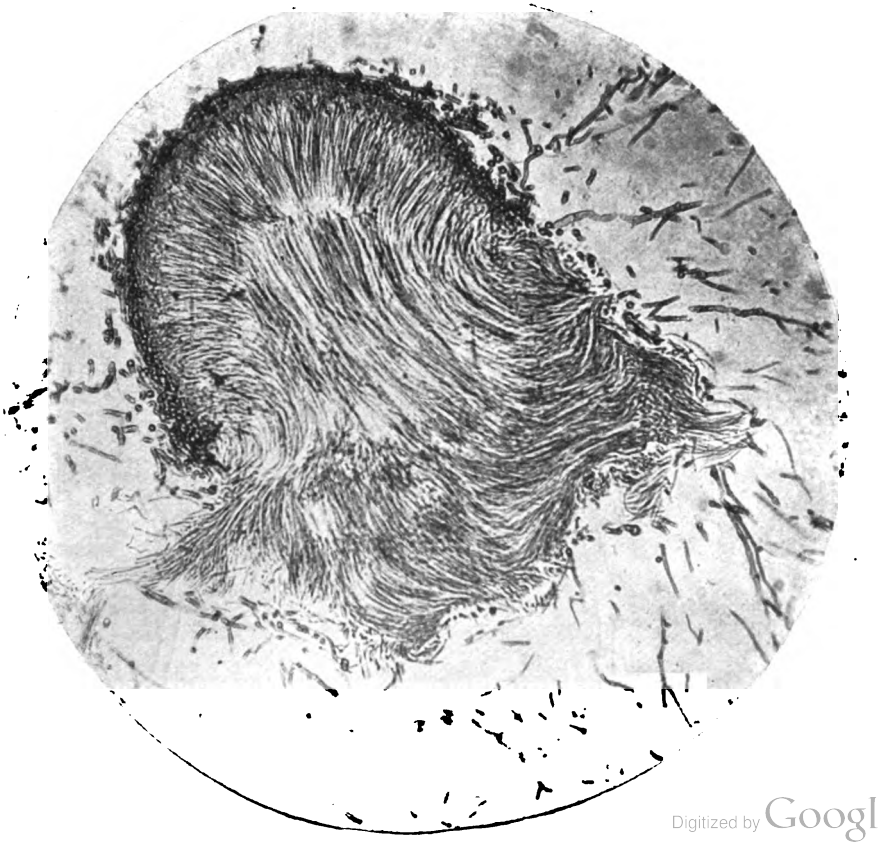

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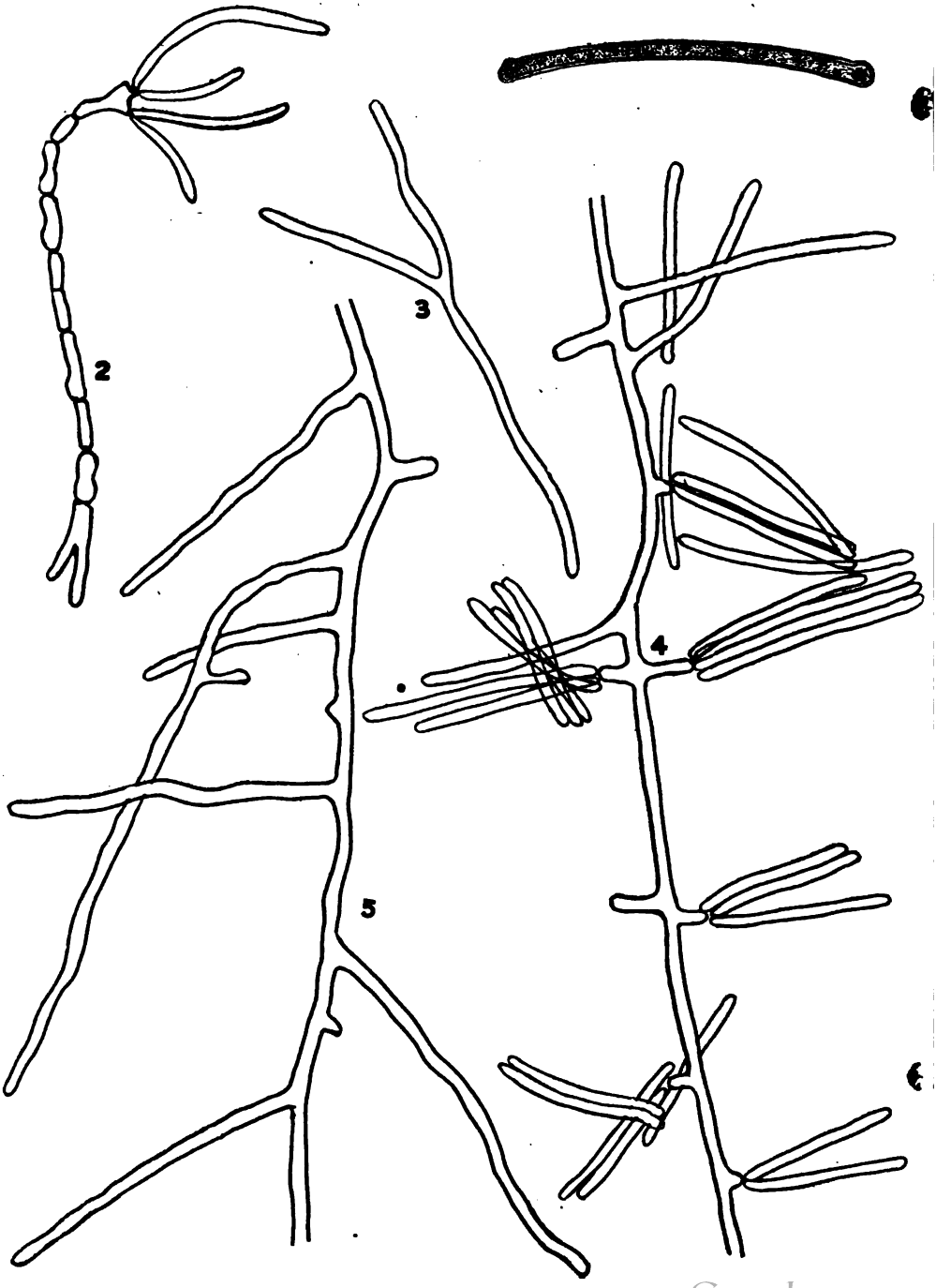


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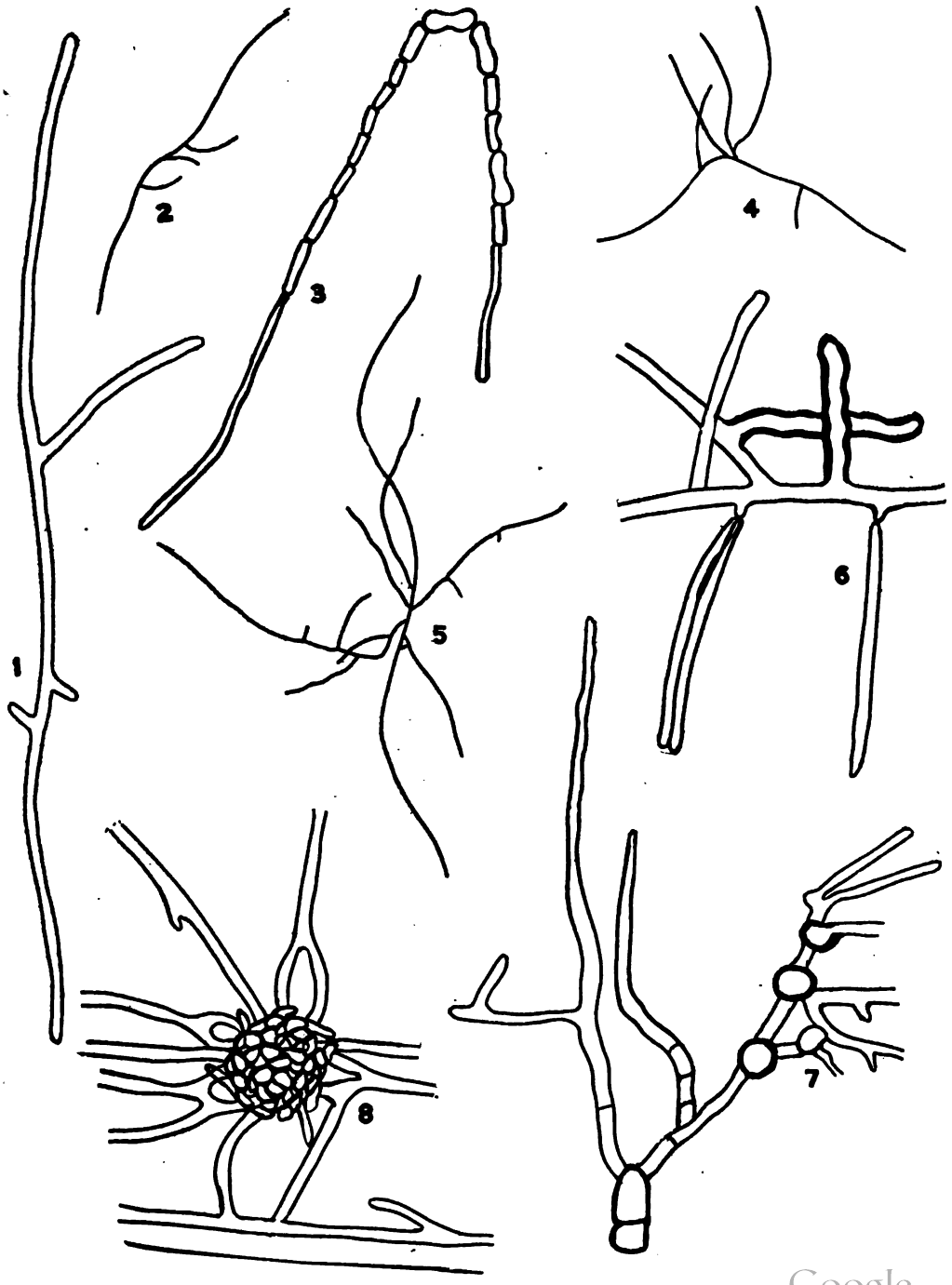
PLATE 9.

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EXPERIMENT STATION

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# SOIL TEMPERATURE

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EAST LANSING, MICHIGAN
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## INTRODUCTION.

In the fall of 1911 an investigation of the general subject of soil temperature was undertaken at this Station. Although the subject had already received a large amount of attention yet it was not considered solved, as our knowledge concerning it appeared very unsatisfactory. This is undoubtedly due to the fact that the problem is a most complex one, as the number of factors influencing it is very great. These factors may be divided into two general groups, (1) the intrinsic and (2) the external. The intrinsic factors are those contained by the soil and comprise the specific heat, heat conductivity, thermal absorption and radiation, specific gravity, texture, structure, moisture content, salt content, topographic position, nature of surface, etc. The external factors include the meteorological elements, chief of which are the air temperature, sunshine, wind velocity, barometric pressure, precipitation, dew point, humidity, etc. The intrinsic factors vary with the different kinds of soil and tend to exert a temporary or permanent controlling influence upon the soil temperature. They are acted upon by the external factors which cause the soil temperature to fluctuate as they themselves vary. Inequality in temperature, therefore, in different kinds of soil for any particular day will depend upon their intrinsic factors, but variation in temperature in these same soils for succeeding days or seasons will depend upon the external factors. Both of these groups of factors may be subdivided into two parts, one part tending to take up or import heat to the soil system and thereby raise its temperature, and the other part tending to give up or take away heat from the same soil system and thereby lower its temperature. These opposing factors are in operation practically all the time. The temperature of a soil, therefore, under field conditions, is the resultant of all these variables and contesting forces.

Most of the previous investigators usually studied only one or two of the intrinsic factors influencing or controlling the soil temperature and then, as a very general rule, deducted general conclusions therefrom as to the importance and controlling effect of these factors upon the soil temperature. There appears to be no one investigator who attacked the subject thoroughly and systematically from all standpoints. As a result wrong conclusions have been drawn, and are being disseminated at present, as to the importance and controlling effect of some of the intrinsic factors upon soil temperature, which have led to erroneous beliefs concerning the difference in temperature in the different classes of soil

In undertaking an investigation of the subject, therefore it was resolved to study it from all standpoints as systematically and thoroughly as possible. The plan finally decided upon consisted (1) of studying individually or in combination most of the chief intrinsic factors affecting the soil temperature, under controlled conditions, (2) investigating

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the influence of these various important factors upon soil temperature under field conditions and (3) ascertaining the relationship between the soil temperature and the different meteorological elements or external factors.

In the report of 1913[1] there were embodied the results of the completed laboratory experiments on the intrinsic factors influencing soil temperature and one year's data of the field experiments. The field experiments have been continued up to the present time, or for four years, and it is the purpose of this bulletin to present the additional data obtained from these experiments and also the final conclusion that might be deducted from the entire investigation.

[1]Technical Bul. 17, Mich. Expt. Sta. 1913.

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## BRIEF REVIEW OF PREVIOUS REPORT.

The investigation on the specific heat of soils showed that the magnitude of this property was about the same for all types of soil, namely gravel, sand, humus loam, clay and peat; this being true both by equal weight as well as by equal volume. By equal weight the magnitude of the value was about 0.200°C and by equal volume about 0.500°C. The specific heat of peat was only about one-half as great as that given to it by previous investigators.

It was concluded that in view of this remarkable equality of the specific heat of the diverse types of soil, this factor exercised practically no influence in causing and maintaining a difference in temperature in these various soils.

Since, however, these diverse types of soil contain different amounts of water, on account of the marked variation in their water-holding capacity, and water possesses five times as great specific heat as the dry soils by equal weight or two times as great by equal volume and its latent heat of evaporation and heat of fusion are tremendously high, it was concluded that the water content of the soil is one of the chief intrinsic factors which might cause a variation in the temperature of these various classes of soil.

The phenomen of heat conductivity was measured in different types of soil, (1) in their dry condition, (2) in their natural state under laboratory conditions and (3) in their natural state under field conditions. It was found that in all these three states the magnitude of heat transference was markedly different in the various types of soil but the order was always the same, namely, gravel manifested the highest heat-transmitting power followed in order by sand, clay, loam and peat, respectively.

It was concluded, however, that even though these diverse classes of soil possess markedly different abilities to propogate heat, yet this factor of heat conductivity is only of secondary and not of primary importance in the control and variation of their temperature. In other words heat conductivity is not a dominant factor and the small variation in average temperature that it would cause in the different types of soil under normal conditions is neutralized or offset by other contrary factors and consequently as an agent itself it cannot cause a permanent variation in average temperature in those soils which possess it in different degrees. Or if it is a dominant factor it opposes some other contrary factor and causes those soils which possess it to the highest degree to have the same average temperature as those that contain it in the least extent.

Under special circumstances, however, such as when a mulch is formed on a cultivated soil heat conductivity might exert a slight predominating and controlling influence on the soil temperature. In such a case, how-

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ever, it is the thin layer of dry soil formed at the surface that plays the leading role rather than the entire tilled layer.

Again in such abnormal soil as peat heat conductivity might predominate and cause a slightly greater cooling at the upper one or two inch depths than in the mineral soils.

The radiating power of the various types of soil was also investigated. It was discovered that color had no effect upon radiation, which is contrary to the popular belief,—but it had a tremendous influence upon the absorption of the solar energy. The various classes of soil radiated slightly differently when in the dry condition, about the same and slightly more when well moistened and that a dry surface or mulch reduced somewhat the amount of radiation. In the dry state sand exhibited the highest radiating power, followed in order by gravel, clay, loam, and peat, respectively. The water, however, manifested far greater radiating capacity than any soil either in the dry or moist condition. The deduction was made that as far as radiation is concerned all the diverse classes of soil lose heat practically to the same extent and that the difference in minimum temperature that is noted in them in the morning or during a period of sudden cold weather is attributed to the difference in their total specific heat.

It was discovered that a high concentration of soil solution tended to raise the soil temperature during the insolation by reducing the amount of evaporation and that during the winter it diminished the lowering of the freezing point and hastened the rate of thawing.

The study on the effect of decomposition of manure on the temperature of soil showed that large applications of this material in the fresh state could raise the soil temperature appreciably, but considering the small amounts that are commonly applied to the soil under field conditions and that a rather high temperature is required for the decomposition process, it was concluded that the amount of heat gained by the soil from this source is absolutely insignificant.

The field studies on the effect of cultivation, noncultivation, and sod upon soil temperatures indicated that during the winter the temperature of the soil under these three cultural conditions was about the same with a slightly higher degree in favor of the sod. In the spring all the soils thawed practically simultaneously and maintained identical average temperature until the vegetation in the sod plot commenced to grow when its temperature began to be lower than that of the other plots, and continued to be smaller until in the fall when the order was reversed. The temperature of the cultivated and uncultivated plots was the same throughout the year except during the spring and summer months when the uncultivated plot had a slightly higher average temperature than the cultivated.

The results from the investigation on the influence of organic matter on the soil temperature showed that those soils containing 1.8, 2.01, 3.32, 5.47, and 6.95% of organic matter thawed practically simultaneously and peat several days later. After complete thawing, however, the peat and the soil containing the least percentage of organic matter and which had a white surface, reached and maintained an appreciably lower average temperature than the other soils throughout the spring and summer months up until in the fall and then this difference disappeared and

all the soils began to have approximately equal degrees of temperature with peat being slightly warmer.

The temperature of the five different types of soil, namely, gravel, sand, humus loam, clay and peat, whose many intrinsic factors were investigated in the laboratory as already discussed, was measured daily throughout a whole year under field conditions, at three different depths. The data yielded by this investigation showed that when all these different types of soil were covered with a thin layer of sand their average temperature was practically the same throughout the year except in the early spring when they were undergoing thawing. At this period their average temperature was markedly different, especially between that of the mineral types and peat, due to their different rate of thawing. After they were all completely thawed, however, their average temperature reached about the same degree and remained practically the same until the next thawing period. Unlike in the spring, in the fall they all cooled at about the same rate. The only other time that their average temperature varied appreciably besides in the spring was whenever there occurred rapid changes in the air temperature, but they would soon reestablish their equilibrium. The amplitude of temperature of course, was very different in them. It was greatest in sand and gravel, followed in order by clay, loam, and peat, respectively.

The results of the last investigation, therefore, indicated that the average temperature of the diverse classes of soil does not vary as much as is popularly believed or as one would think, in view of the great variation of the intrinsic factors in them.

## ADDITIONAL EXPERIMENTAL DATA ON THE TEMPERATURE OF DIFFERENT TYPES OF SOIL AT DIFFERENT DEPTHS AND UNDER DIFFERENT SURFACE CONDITIONS FOR 1913, 1914, AND 1915.[2]

### PLAN OF THE EXPERIMENT.

As described in the first report this investigation was prepared by making a long trench a little over three feet wide on a smooth and slightly rolling piece of ground, covering the bottom with a thin layer of a sandy soil so as to be uniform throughout, then placing into this trench, about one foot apart, wooden boxes 3x3x3 feet without bottom or top, and then filling these boxes with five different types of soil, namely, gravel, sand, clay, humus loam, and peat. After they were flooded with water several times and a certain length of period was allowed to elapse in order that they might settle, a study of their temperature was commenced. Their temperature was measured at three different depths, 6, 12, and 18, or 2, 4, and 6 inches, three times a day, usually at about 7 A. M. 12 M. and 6 P. M. every day throughout the year except Sundays, by means of electric resistance thermometers. These instruments consisted of resist-

[2]The author wishes to express his deepest gratitude and indebtedness to Mr. M. Wolkoff, a graduate student, for his most loyal and excellent intelligent support in the conduct of the following experiments and in the preparation of the many laborious tables.

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ance bulbs and 35 feet wire leads. The leads were incased in lead pipe so as to keep them dry and well insulated. The ends of these leads were run into a small house specially constructed for the purpose. In this house there was kept, on a permanent stand, a balance indicator upon which the temperature was read.

During the first year, from Dec. 1, 1911 to Nov. 30, 1912, the surface of all the five different types of soil was covered with a very thin layer of sand in order to eliminate their differential factor of color. The temperature during this period was also measured by an indicator graduated to only 1°F.

During the second year, from December 1, 1912 to November 30, 1913, the thin layer of sand was removed from the surface of all the soils and consequently their natural surface was exposed to the atmosphere and allowed to play its role. Beginning with this year also the old balance indicator was replaced by a new one which was graduated to 0.5°F and thus more sensitive than the first.

In the third year, from December 1, 1913 to November 30, 1914, all the soils were again covered by a thin layer of sand.

At the beginning of the fourth year, however, from December 1, 1914 to November 30, 1915, the surfaces of all the soils were again uncovered, and the thermometers were removed from the 6, 12 and 18 inch depths at which they had remained from the beginning of the experiment, and placed at 2, 4, and 6 inch depths, respectively. During the warm part of this year the surface temperature was also taken by means of mercury thermometers having extremely small bulbs.

It was stated above that the temperature records were taken at 7 A. M., 12 M. and 6 P. M. These periods, however, were changed somewhat during the year in order to obtain as true an average and range of temperature as possible. During the warm part of the year, when the sun rose early in the morning, the temperature records were taken at about 6 A. M., 1 P. M. and 5 P. M., while during the cold part of the year they were taken at about 7 A. M., 12 M. and 6 P. M. The daily average temperature, therefore, is composed of these three diurnal readings, and the daily amplitude, the difference between the highest and lowest temperature recorded during the day.

Even though the temperature was recorded three times a day it cannot be claimed, however, that it gives the absolute average and range of temperature for all depths and for all soils. This is at once obvious from the fact that the real maximum and minimum temperatures at the various depths of the same and of different soils are attained at entirely different periods of the day. The three diurnal records, however, do give a very close approximation of the true daily average and fluctuation of temperature for all soils and for all depths. Furthermore, since these three diurnal records have been taken almost every day for four years the average for the month, season or year is exceedingly close, if not exactly, the true average and range of temperature.

As already mentioned the previous report[3], contained all the data for the first year. In the present report will be presented the results for the following three years, or from December 1, 1912, to November 30, 1915.

[3]Technical Bul. 17, Mich. Expt. Sta., 1913.

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## THE DAILY AND MONTHLY AVERAGE TEMPERATURE FOR 1913, 1914 AND 1815.

## BEGINNING WITH THE SECOND YEAR.

TABLE 1.—AVERAGE TEMPERATURES OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, DECEMBER, 1912 (a)

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 | 42.77 | 42.10 | 41.17 | 42.77 | 42.17 | 41.60 | 40.23 | 39.23 | 40.10 | 41.50 | 39.70 | 40.03 | 37.53 | 37.63 | 40.63 |
| 3 | 37.29 | 38.73 | 41.13 | 36.90 | 39.10 | 41.53 | 37.63 | 39.93 | 41.37 | 37.77 | 40.10 | 41.33 | 37.73 | 38.50 | 40.83 |
| 4 | 37.90 | 38.43 | 39.77 | 37.73 | 38.43 | 40.03 | 37.03 | 38.67 | 40.50 | 37.50 | 38.77 | 40.00 | 36.47 | 38.23 | 40.67 |
| 5 | 38.10 | 38.53 | 39.83 | 37.87 | 38.50 | 40.13 | 37.03 | 38.63 | 40.37 | 37.43 | 38.70 | 39.87 | 36.47 | 37.97 | 40.43 |
| 6 | 40.70 | 41.93 | 42.00 | 40.57 | 41.70 | 42.23 | 40.50 | 40.87 | 41.27 | 40.57 | 41.10 | 41.20 | 39.43 | 38.77 | 40.97 |
| 7 | 35.50 | 37.43 | 40.13 | 36.00 | 37.57 | 40.43 | 36.43 | 39.40 | 41.23 | 36.40 | 39.30 | 40.80 | 37.57 | 38.87 | 40.87 |
| 9 | 33.00 | 34.90 | 38.10 | 33.47 | 35.33 | 38.50 | 34.10 | 37.27 | 39.63 | 33.87 | 36.97 | 38.77 | 35.30 | 38.07 | 40.80 |
| 10 | 32.20 | 34.10 | 37.10 | 32.60 | 34.50 | 37.70 | 33.33 | 36.43 | 38.80 | 33.07 | 36.17 | 37.97 | 34.53 | 37.30 | 39.77 |
| 11 | 32.40 | 34.07 | 36.90 | 32.43 | 34.50 | 37.43 | 33.10 | 35.97 | 38.27 | 32.90 | 35.73 | 37.47 | 33.87 | 36.67 | 39.60 |
| 12 | 30.67 | 32.90 | 36.13 | 30.83 | 33.40 | 36.90 | 32.53 | 35.57 | 37.87 | 32.20 | 35.27 | 37.07 | 33.40 | 36.20 | 38.90 |
| 13 | 29.87 | 31.90 | 35.27 | 30.00 | 32.47 | 36.00 | 31.50 | 34.73 | 37.17 | 31.23 | 34.40 | 36.27 | 32.63 | 35.40 | 38.43 |
| 14 | 29.97 | 31.80 | 34.70 | 29.83 | 32.10 | 35.53 | 30.93 | 34.07 | 36.60 | 30.93 | 33.77 | 35.67 | 32.27 | 34.83 | 37.93 |
| 16 | 30.93 | 32.00 | 34.77 | 31.10 | 32.83 | 35.50 | 31.23 | 33.87 | 36.20 | 31.13 | 33.67 | 35.33 | 32.13 | 34.50 | 37.27 |
| 17 | 31.27 | 32.50 | 34.90 | 32.00 | 33.27 | 35.67 | 31.37 | 33.97 | 36.30 | 31.50 | 33.80 | 35.33 | 32.17 | 34.40 | 37.20 |
| 18 | 32.37 | 33.43 | 35.77 | 33.30 | 34.43 | 36.47 | 32.10 | 34.63 | 36.73 | 32.30 | 34.53 | 35.90 | 32.80 | 34.83 | 37.57 |
| 19 | 32.63 | 33.73 | 35.83 | 33.13 | 34.70 | 36.63 | 32.27 | 34.80 | 36.73 | 32.60 | 34.83 | 36.23 | 32.83 | 34.87 | 37.57 |
| 20 | 32.87 | 34.03 | 35.87 | 33.00 | 34.37 | 36.53 | 32.23 | 34.63 | 36.63 | 32.63 | 34.70 | 36.03 | 32.83 | 34.70 | 37.37 |
| 21 | 33.00 | 34.00 | 35.83 | 32.97 | 34.47 | 36.40 | 32.33 | 34.77 | 36.50 | 32.77 | 34.83 | 35.93 | 32.87 | 34.73 | 37.27 |
| 23 | 31.93 | 33.03 | 35.23 | 31.60 | 33.33 | 35.87 | 31.67 | 34.13 | 35.87 | 32.07 | 34.27 | 35.53 | 32.13 | 33.97 | 36.60 |
| 24 | 31.40 | 32.73 | 34.73 | 31.23 | 32.87 | 35.10 | 31.13 | 33.53 | 35.63 | 31.37 | 33.53 | 35.00 | 31.53 | 33.60 | 36.17 |
| 26 | 31.80 | 33.07 | 35.07 | 31.57 | 33.00 | 35.50 | 31.43 | 34.00 | 35.80 | 31.70 | 33.97 | 35.27 | 32.03 | 34.00 | 36.50 |
| 27 | 32.43 | 33.50 | 35.30 | 32.03 | 33.53 | 35.83 | 31.97 | 34.30 | 36.17 | 32.33 | 34.30 | 35.73 | 32.43 | 34.30 | 36.93 |
| 28 | 31.53 | 32.83 | 34.90 | 31.50 | 33.00 | 35.27 | 31.43 | 33.77 | 35.60 | 31.70 | 33.90 | 35.27 | 32.00 | 33.83 | 36.47 |
| 30 | 31.93 | 33.07 | 34.97 | 32.10 | 33.07 | 35.23 | 31.43 | 33.70 | 35.57 | 31.87 | 33.87 | 35.07 | 31.90 | 33.63 | 36.23 |
| 31 | 31.80 | 32.93 | 34.73 | 31.73 | 33.03 | 35.03 | 31.27 | 33.50 | 35.37 | 31.80 | 33.67 | 34.97 | 31.70 | 33.47 | 36.10 |
| Monthly average | 33.45 | 34.71 | 36.81 | 33.53 | 35.03 | 37.32 | 33.45 | 35.77 | 37.69 | 33.65 | 35.75 | 37.12 | 33.86 | 35.73 | 38.36 |

(a) Unless otherwise stated the temperature figures in all the tables are expressed in Fahrenheit degrees.

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TABLE 2.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JANUARY, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 31.63 | 32.73 | 34.23 | 31.53 | 32.87 | 34.83 | 31.13 | 33.17 | 34.97 | 31.57 | 33.37 | 34.73 | 31.47 | 33.13 | 35.80 |
| 2 | 31.77 | 32.83 | 34.30 | 31.67 | 32.93 | 34.97 | 31.13 | 33.23 | 35.00 | 31.63 | 33.40 | 34.70 | 31.47 | 33.23 | 35.80 |
| 3 | 32.40 | 33.23 | 34.97 | 32.17 | 33.53 | 35.37 | 31.57 | 33.67 | 35.30 | 32.27 | 34.00 | 35.07 | 31.87 | 33.73 | 36.10 |
| 4 | 32.43 | 33.30 | 34.90 | 32.17 | 33.50 | 35.33 | 31.83 | 33.80 | 35.37 | 32.20 | 34.03 | 35.10 | 31.97 | 33.57 | 35.93 |
| 6 | 31.57 | 32.70 | 34.43 | 31.43 | 32.87 | 34.80 | 31.10 | 33.23 | 35.10 | 31.43 | 33.43 | 34.80 | 31.47 | 33.20 | 35.90 |
| 7 | 32.43 | 33.33 | 35.03 | 32.50 | 33.50 | 35.37 | 31.63 | 33.90 | 35.60 | 32.33 | 34.10 | 35.40 | 32.17 | 34.00 | 36.47 |
| 8 | 32.70 | 33.60 | 35.10 | 32.50 | 33.80 | 35.70 | 31.80 | 34.10 | 35.80 | 32.40 | 34.20 | 35.10 | 32.20 | 34.10 | 36.50 |
| 9 | 31.80 | 32.95 | 34.35 | 31.65 | 32.90 | 34.85 | 31.20 | 33.30 | 34.95 | 31.60 | 33.30 | 34.75 | 31.50 | 32.80 | 35.70 |
| 10 | 32.03 | 33.00 | 34.53 | 31.83 | 32.97 | 34.93 | 31.53 | 33.47 | 35.10 | 31.87 | 33.43 | 34.67 | 31.63 | 33.30 | 35.83 |
| 11 | 32.13 | 33.07 | 34.43 | 31.80 | 33.03 | 34.97 | 31.30 | 33.30 | 34.97 | 31.83 | 33.40 | 34.67 | 31.70 | 33.23 | 35.67 |
| 13 | 32.57 | 33.53 | 34.90 | 32.13 | 33.53 | 35.20 | 31.60 | 33.83 | 35.13 | 32.10 | 33.83 | 34.93 | 31.90 | 33.47 | 35.97 |
| 14 | 32.50 | 33.40 | 34.93 | 32.23 | 33.50 | 35.20 | 31.50 | 33.60 | 35.07 | 32.00 | 33.77 | 35.07 | 32.10 | 33.63 | 35.83 |
| 15 | 32.70 | 33.40 | 34.93 | 32.20 | 33.53 | 35.07 | 31.47 | 33.63 | 35.13 | 32.03 | 33.83 | 34.83 | 31.73 | 33.27 | 35.73 |
| 16 | 32.63 | 33.53 | 34.87 | 32.10 | 32.97 | 34.23 | 31.80 | 33.77 | 35.17 | 32.10 | 33.83 | 34.97 | 31.83 | 33.67 | 35.87 |
| 17 | 32.33 | 33.37 | 34.90 | 32.07 | 33.97 | 34.77 | 31.90 | 33.70 | 35.03 | 32.20 | 33.90 | 34.87 | 31.90 | 33.33 | 35.73 |
| 18 | 32.27 | 33.80 | 34.83 | 32.17 | 33.63 | 34.97 | 31.87 | 33.60 | 35.17 | 32.17 | 34.00 | 35.00 | 32.00 | 33.30 | 35.60 |
| 20 | 32.97 | 33.93 | 35.03 | 33.03 | 34.03 | 35.57 | 32.13 | 33.87 | 35.50 | 32.73 | 34.10 | 35.27 | 32.13 | 33.53 | 35.90 |
| 21 | 33.48 | 34.13 | 35.40 | 33.23 | 34.23 | 35.60 | 32.27 | 34.10 | 35.60 | 32.87 | 34.30 | 35.33 | 32.13 | 33.50 | 35.97 |
| 22 | 33.27 | 34.17 | 35.33 | 33.17 | 34.23 | 35.50 | 31.97 | 33.90 | 35.40 | 32.80 | 34.07 | 35.10 | 32.03 | 33.47 | 35.63 |
| 23 | 33.17 | 34.10 | 35.37 | 33.03 | 34.10 | 35.50 | 31.97 | 33.83 | 35.20 | 32.80 | 34.17 | 35.13 | 32.00 | 33.30 | 35.70 |
| 24 | 33.13 | 34.00 | 35.27 | 33.00 | 34.00 | 35.30 | 32.00 | 33.87 | 35.20 | 32.87 | 34.23 | 35.17 | 32.03 | 33.37 | 35.70 |
| 25 | 33.27 | 34.10 | 35.30 | 33.10 | 34.07 | 35.53 | 32.07 | 33.97 | 35.33 | 32.93 | 34.20 | 35.23 | 32.03 | 33.37 | 35.80 |
| 27 | 33.10 | 33.90 | 35.13 | 32.83 | 33.93 | 35.13 | 31.90 | 33.93 | 35.07 | 32.80 | 34.00 | 35.00 | 31.80 | 33.07 | 35.53 |
| 28 | 32.50 | 33.43 | 34.93 | 31.87 | 33.37 | 35.03 | 31.93 | 33.80 | 35.07 | 32.63 | 34.03 | 35.03 | 31.90 | 33.17 | 35.53 |
| 29 | 31.13 | 32.90 | 34.73 | 29.70 | 32.67 | 34.80 | 31.47 | 33.83 | 35.13 | 31.93 | 33.90 | 34.90 | 30.97 | 33.23 | 35.63 |
| 30 | 31.03 | 32.20 | 34.03 | 30.67 | 32.13 | 34.20 | 31.10 | 33.17 | 34.77 | 31.33 | 33.20 | 34.27 | 30.87 | 32.87 | 35.07 |
| 31 | 31.67 | 32.50 | 33.93 | 31.30 | 32.17 | 33.90 | 31.13 | 33.20 | 34.80 | 31.70 | 33.17 | 34.30 | 31.30 | 32.93 | 35.23 |
| Average | 32.39 | 33.38 | 34.82 | 32.11 | 33.41 | 35.08 | 31.64 | 33.66 | 35.18 | 32.19 | 33.82 | 34.94 | 31.78 | 33.36 | 35.78 |

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TABLE 3.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, FEBRUARY, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 29.26 | 32.23 | 34.16 | 30.86 | 32.80 | 34.30 | 31.00 | 33.23 | 34.90 | 31.26 | 33.26 | 34.50 | 29.63 | 33.10 | 35.23 |
| 3 | 28.63 | 30.36 | 33.13 | 27.83 | 30.93 | 33.53 | 29.26 | 32.63 | 34.20 | 29.30 | 32.46 | 33.80 | 28.20 | 32.40 | 35.00 |
| 4 | 27.66 | 30.10 | 33.16 | 26.00 | 30.63 | 33.70 | 28.96 | 32.76 | 34.30 | 29.13 | 32.53 | 33.86 | 27.36 | 32.80 | 35.06 |
| 5 | 24.33 | 27.96 | 32.56 | 21.30 | 28.23 | 33.10 | 26.26 | 32.00 | 33.86 | 26.66 | 31.86 | 33.16 | 23.73 | 32.03 | 34.56 |
| 6 | 22.96 | 26.26 | 31.90 | 19.86 | 26.63 | 32.73 | 24.66 | 31.46 | 33.60 | 25.06 | 31.36 | 33.00 | 21.80 | 31.73 | 34.40 |
| 7 | 25.86 | 27.70 | 31.73 | 23.86 | 28.00 | 32.76 | 25.93 | 31 30 | 33.43 | 26.20 | 30.96 | 32.83 | 24.13 | 31.63 | 34.46 |
| 8 | 26.70 | 28.20 | 31.20 | 25.83 | 28.73 | 32.06 | 26.40 | 30.83 | 33.03 | 26.40 | 30.16 | 32.30 | 25.46 | 31.16 | 34.00 |
| 10 | 25.30 | 27.20 | 31.20 | 24.06 | 28.03 | 31.90 | 25.80 | 30.40 | 32.86 | 26.06 | 29.96 | 31.96 | 24.16 | 30.56 | 33.66 |
| 11 | 28.20 | 29.06 | 30.66 | 28.40 | 29.50 | 31.20 | 27.46 | 29.86 | 31.76 | 27.93 | 29.73 | 31.26 | 27.80 | 30.16 | 33.10 |
| 12 | 24.30 | 26.86 | 30.96 | 22.10 | 27.46 | 31.70 | 25.36 | 30.13 | 32.33 | 25.70 | 29.76 | 31.56 | 23.03 | 29.86 | 33.40 |
| 13 | 22.43 | 25.20 | 30.46 | 19.60 | 25.96 | 30.90 | 23.30 | 29.43 | 32.26 | 23.93 | 28.93 | 31.36 | 20.50 | 28.30 | 33.06 |
| 14 | 24.93 | 26.53 | 30.23 | 23.73 | 27.23 | 30.90 | 24.80 | 29.03 | 32.10 | 25.10 | 28.53 | 31.03 | 23.50 | 28.03 | 32.70 |
| 15 | 29.00 | 29.63 | 30.66 | 29.13 | 29.93 | 31 00 | 27.90 | 29.60 | 31.43 | 28.80 | 29.23 | 30.76 | 28.13 | 29.16 | 32.40 |
| 17 | 29.30 | 30 03 | 31.10 | 29.06 | 30.03 | 31.20 | 28.46 | 30.03 | 31.53 | 28.66 | 29.90 | 30.93 | 28.40 | 29.73 | 32.30 |
| 18 | 28.23 | 29.27 | 31.03 | 27.57 | 29.20 | 31.23 | 27.87 | 29.97 | 31.50 | 28.37 | 29.97 | 30.93 | 27.17 | 29.63 | 32.27 |
| 19 | 30.57 | 30.70 | 31.10 | 30.70 | 31.07 | 31.43 | 29.17 | 30.07 | 31.50 | 29.33 | 29.83 | 31.07 | 30.10 | 30.17 | 32.50 |
| 20 | 31.57 | 31.57 | 31.47 | 31.37 | 31.60 | 31.63 | 29.93 | 30.97 | 31.70 | 30.40 | 30.73 | 31.23 | 30.60 | 30.53 | 32.33 |
| 21 | 32.17 | 32.57 | 32.20 | 31.97 | 32.30 | 32.47 | 30.97 | 31.57 | 32.53 | 31.57 | 31.43 | 32.00 | 31.43 | 31.20 | 32.97 |
| 22 | 31.83 | 31.93 | 32.03 | 31.63 | 31.93 | 31.93 | 30.70 | 31.20 | 32.13 | 31.27 | 31.23 | 31.70 | 31.27 | 30.97 | 32.70 |
| 24 | 32.00 | 32.00 | 32.05 | 31.75 | 32.00 | 32.15 | 31.00 | 31.30 | 32.05 | 31.65 | 31.65 | 31.85 | 31.35 | 31.15 | 32.85 |
| 25 | 31.57 | 31.83 | 31.67 | 31.43 | 31.73 | 31.97 | 30.67 | 31.07 | 31.87 | 30.90 | 31.37 | 31.60 | 31.13 | 31.00 | 32.67 |
| 26 | 31.63 | 31.73 | 31.77 | 31.30 | 31.60 | 31.97 | 30.47 | 31.10 | 31.77 | 30.63 | 31.23 | 31.63 | 31.23 | 31.03 | 32.50 |
| 27 | 31.57 | 31.77 | 31.97 | 31.53 | 31.83 | 32.33 | 30.63 | 31.30 | 32.10 | 30.90 | 31.13 | 31.70 | 31.33 | 31.13 | 32.97 |
| 28 | 31.73 | 31.97 | 31.83 | 31.47 | 31.80 | 32.10 | 30.47 | 31.20 | 31.90 | 30.83 | 31.27 | 31.70 | 31.10 | 31.00 | 32.33 |
| **Average** | **28.40** | **29.70** | **31.67** | **28.01** | **29.96** | **32.09** | **28.23** | **30.94** | **32.53** | **28.59** | **30.77** | **31.99** | **27.61** | **30.77** | **33.31** |

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TABLE 4.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, MARCH, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18 |
| 1 | 31.47 | 31.70 | 31.80 | 31.43 | 31.67 | 32.13 | 30.17 | 31.07 | 31.77 | 30.57 | 31.27 | 31.47 | 30.90 | 30.87 | 32.23 |
| 3 | 31.60 | 31.77 | 31.87 | 30.87 | 31.63 | 32.17 | 30.00 | 31.10 | 31.77 | 30.27 | 31.13 | 31.57 | 30.13 | 30.87 | 32.33 |
| 4 | 31.77 | 31.93 | 32.20 | 31.17 | 31.80 | 32.43 | 30.47 | 31.40 | 32.23 | 30.87 | 31.47 | 31.90 | 30.53 | 31.07 | 32.70 |
| 5 | 31.77 | 32.10 | 32.33 | 30.87 | 31.77 | 32.60 | 30.13 | 31.23 | 32.00 | 30.70 | 31.30 | 31.77 | 30.13 | 30.93 | 32.57 |
| 6 | 31.60 | 31.87 | 32.20 | 31.27 | 31.70 | 32.70 | 30.07 | 31.20 | 31.97 | 30.43 | 31.33 | 31.77 | 30.03 | 30.83 | 32.63 |
| 7 | 31.70 | 32.00 | 32.43 | 30.70 | 31.70 | 32.70 | 30.00 | 31.20 | 32.10 | 30.40 | 31.53 | 32.03 | 29.33 | 30.93 | 32.73 |
| 8 | 31.47 | 32.00 | 32.50 | 30.47 | 31.53 | 32.70 | 29.93 | 31.27 | 32.13 | 30.20 | 31.37 | 31.97 | 28.93 | 30.80 | 32.83 |
| 10 | 31.70 | 32.03 | 32.63 | 31.60 | 32.00 | 32.47 | 30.60 | 31.27 | 32.17 | 31.20 | 31.57 | 31.93 | 30.97 | 31.07 | 32.77 |
| 11 | 31.73 | 32.00 | 32.50 | 31.57 | 31.87 | 32.40 | 30.53 | 31.33 | 32.30 | 31.40 | 31.70 | 32.10 | 31.23 | 31.07 | 32.83 |
| 12 | 32.33 | 32.53 | 33.00 | 32.03 | 32.40 | 32.87 | 31.07 | 31.83 | 32.77 | 31.63 | 32.00 | 32.50 | 31.70 | 31.50 | 33.10 |
| 13 | 32.30 | 32.60 | 32.90 | 31.90 | 32.27 | 32.87 | 31.10 | 31.70 | 32.60 | 31.80 | 31.93 | 32.63 | 31.73 | 31.43 | 32.97 |
| 15 | 32.90 | 32.50 | 32.97 | 32.57 | 32.30 | 33.03 | 31.73 | 31.90 | 32.53 | 32.50 | 32.17 | 32.50 | 32.17 | 31.70 | 33.13 |
| 17 | 31.77 | 32.43 | 32.90 | 31.53 | 32.07 | 32.97 | 31.63 | 31.80 | 32.57 | 32.17 | 32.07 | 32.43 | 32.10 | 31.63 | 33.00 |
| 18 | 32.07 | 32.23 | 32.77 | 32.17 | 32.00 | 32.80 | 31.43 | 31.57 | 32.23 | 31.97 | 31.87 | 32.10 | 31.77 | 31.33 | 32.77 |
| 19 | 38.87 | 33.80 | 33.00 | 39.37 | 33.70 | 33.03 | 32.67 | 31.50 | 32.27 | 33.43 | 32.13 | 32.43 | 32.00 | 31.53 | 32.93 |
| 20 | 43.27 | 37.90 | 35.03 | 43.67 | 37.90 | 35.30 | 36.13 | 31.93 | 32.70 | 37.93 | 32.27 | 32.70 | 32.10 | 31.63 | 33.03 |
| 21 | 36.37 | 36.34 | 35.70 | 36.47 | 36.27 | 35.80 | 33.43 | 32.03 | 32.77 | 34.87 | 32.33 | 32.77 | 32.20 | 31.90 | 33.27 |
| 22 | 33.73 | 34.03 | 34.50 | 33.70 | 34.13 | 34.57 | 32.07 | 32.10 | 32.93 | 33.13 | 32.37 | 32.80 | 32.27 | 31.90 | 33.23 |
| 24 | 46.57 | 39.80 | 35.83 | 46.17 | 38.77 | 35.73 | 41.23 | 31.63 | 32.37 | 42.20 | 32.00 | 32.60 | 31.93 | 31.60 | 33.17 |
| 25 | 35.20 | 37.40 | 37.60 | 35.07 | 37.33 | 37.37 | 33.00 | 31.90 | 32.90 | 34.83 | 32.63 | 32.73 | 31.97 | 31.70 | 33.13 |
| 26 | 32.83 | 34.87 | 35.73 | 32.47 | 34.73 | 35.67 | 31.40 | 31.53 | 32.80 | 32.40 | 32.90 | 33.17 | 31.63 | 31.20 | 32.87 |
| 27 | 32.83 | 34.33 | 35.27 | 32.50 | 34.17 | 35.30 | 31.50 | 31.67 | 32.93 | 32.47 | 33.03 | 33.47 | 31.83 | 31.40 | 33.07 |
| 28 | 32.77 | 33.97 | 34.90 | 32.33 | 33.87 | 34.87 | 31.40 | 31.70 | 32.93 | 32.53 | 33.17 | 33.53 | 31.73 | 31.50 | 33.23 |
| 29 | 32.67 | 33.50 | 34.47 | 32.07 | 33.37 | 34.37 | 31.03 | 31.97 | 33.10 | 32.70 | 33.60 | 33.87 | 32.03 | 31.73 | 33.37 |
| 31 | 42.75 | 39.70 | 37.75 | 42.93 | 39.13 | 37.10 | 39.67 | 31.17 | 32.70 | 41.17 | 37.03 | 35.60 | 31.83 | 31.07 | 32.87 |
| Average | 34.16 | 33.81 | 33.78 | 33.88 | 33.60 | 33.84 | 32.10 | 31.56 | 32.46 | 32.95 | 32.25 | 32.57 | 31.33 | 31.33 | 32.91 |

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TABLE 5.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, APRIL, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 43.97 | 40.30 | 39.03 | 43.87 | 39.80 | 38.97 | 39.00 | 32.97 | 34.67 | 40.83 | 38.63 | 37.77 | 32.53 | 31.97 | 34.00 |
| 2 | 40.70 | 40.40 | 39.63 | 40.17 | 39.93 | 39.30 | 38.57 | 37.20 | 36.27 | 39.43 | 38.90 | 37.97 | 32.47 | 32.00 | 33.83 |
| 3 | 45.77 | 41.23 | 39.90 | 45.23 | 40.60 | 39.80 | 42.93 | 38.77 | 37.90 | 42.77 | 39.03 | 38.20 | 33.00 | 31.80 | 33.97 |
| 4 | 50.67 | 46.97 | 42.90 | 49.97 | 46.03 | 42.67 | 49.97 | 42.97 | 39.67 | 49.53 | 43.13 | 40.67 | 34.90 | 32.20 | 34.40 |
| 5 | 40.47 | 41.70 | 42.20 | 40.57 | 41.77 | 42.30 | 40.33 | 42.43 | 40.97 | 40.57 | 42.33 | 41.67 | 33.10 | 32.13 | 34.77 |
| 7 | 39.97 | 39.97 | 40.37 | 40.10 | 40.20 | 40.43 | 38.07 | 39.70 | 39.80 | 38.03 | 39.37 | 39.60 | 33.13 | 32.00 | 35.20 |
| 8 | 42.00 | 40.00 | 39.97 | 41.97 | 39.70 | 40.20 | 38.97 | 39.37 | 39.57 | 38.60 | 38.90 | 39.43 | 32.97 | 31.90 | 35.43 |
| 9 | 40.27 | 40.00 | 40.23 | 40.10 | 39.87 | 39.87 | 37.53 | 39.20 | 39.07 | 38.23 | 39.23 | 38.97 | 32.77 | 31.67 | 35.10 |
| 10 | 41.90 | 40.30 | 40.10 | 41.63 | 40.23 | 40.20 | 39.87 | 39.13 | 39.17 | 40.27 | 39.17 | 39.07 | 33.27 | 31.83 | 35.10 |
| 11 | 43.10 | 42.37 | 41.23 | 42.97 | 42.13 | 41.13 | 42.60 | 40.87 | 39.63 | 42.77 | 41.00 | 40.07 | 35.00 | 31.97 | 35.50 |
| 12 | 40.73 | 41.13 | 41.00 | 40.30 | 40.93 | 40.93 | 40.57 | 40.87 | 40.20 | 40.87 | 41.00 | 40.50 | 34.23 | 32.00 | 35.43 |
| 14 | 46.37 | 43.17 | 42.17 | 46.40 | 42.73 | 42.03 | 43.47 | 41.67 | 40.87 | 43.00 | 41.53 | 41.20 | 35.07 | 31.97 | 36.17 |
| 15 | 48.23 | 43.50 | 42.43 | 48.00 | 43.10 | 42.27 | 44.40 | 42.03 | 41.13 | 43.63 | 41.80 | 41.60 | 35.57 | 32.37 | 36.43 |
| 16 | 52.00 | 46.23 | 43.70 | 51.03 | 45.57 | 43.53 | 47.70 | 43.23 | 41.43 | 46.93 | 43.30 | 42.03 | 36.63 | 32.20 | 36.73 |
| 17 | 53.03 | 47.63 | 45.27 | 51.67 | 46.50 | 44.63 | 48.70 | 44.50 | 42.93 | 48.40 | 44.67 | 43.37 | 37.33 | 32.57 | 37.30 |
| 18 | 57.87 | 51.00 | 46.73 | 56.17 | 49.50 | 46.20 | 53.47 | 46.43 | 43.83 | 52.87 | 46.80 | 44.77 | 39.73 | 32.73 | 37.30 |
| 19 | 52.40 | 50.00 | 48.00 | 51.60 | 49.13 | 47.40 | 49.57 | 47.80 | 45.07 | 49.77 | 48.03 | 46.47 | 40.57 | 33.10 | 38.00 |
| 21 | 48.60 | 46.27 | 46.07 | 47.47 | 45.87 | 45.67 | 45.77 | 45.73 | 44.97 | 45.63 | 45.80 | 45.37 | 41.00 | 39.37 | 41.47 |
| 22 | 55.47 | 49.13 | 46.47 | 54.30 | 48.20 | 46.27 | 51.63 | 46.27 | 44.70 | 51.13 | 46.13 | 45.13 | 45.63 | 41.93 | 42.37 |
| 23 | 61.57 | 54.00 | 49.53 | 61.27 | 52.93 | 48.83 | 58.43 | 49.63 | 46.40 | 57.37 | 49.83 | 47.60 | 51.47 | 45.00 | 44.00 |
| 24 | 62.57 | 55.97 | 51.50 | 62.13 | 54.83 | 50.73 | 59.87 | 51.83 | 48.00 | 58.37 | 52.03 | 49.30 | 54.37 | 47.37 | 45.23 |
| 25 | 58.43 | 56.50 | 53.23 | 57.90 | 55.63 | 52.70 | 57.60 | 54.07 | 49.87 | 57.40 | 54.20 | 51.53 | 55.87 | 50.13 | 47.17 |
| 26 | 49.97 | 51.03 | 50.77 | 49.57 | 50.50 | 50.33 | 50.63 | 51.67 | 49.73 | 50.90 | 51.60 | 50.70 | 51.97 | 49.03 | 48.17 |
| 28 | 46.43 | 45.70 | 46.43 | 46.77 | 45.63 | 46.43 | 45.97 | 46.83 | 47.37 | 45.87 | 46.57 | 47.10 | 45.27 | 48.20 | 48.47 |
| 29 | 50.73 | 46.73 | 46.33 | 51.13 | 46.80 | 46.60 | 47.70 | 46.37 | 46.50 | 46.97 | 46.27 | 46.57 | 46.73 | 47.60 | 47.90 |
| 30 | 56.67 | 50.30 | 48.13 | 56.23 | 49.90 | 48.07 | 52.53 | 47.97 | 46.73 | 51.30 | 47.63 | 47.07 | 49.23 | 47.60 | 47.53 |
| Average | 48.84 | 45.83 | 44.36 | 48.40 | 45.31 | 44.13 | 46.38 | 43.83 | 42.56 | 46.21 | 44.11 | 43.22 | 39.76 | 37.06 | 39.11 |

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TABLE 6.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, MAY, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 62.00 | 54.33 | 50.53 | 61.27 | 53.57 | 50.20 | 57.47 | 50.33 | 47.83 | 56.20 | 50.47 | 48.63 | 52.90 | 48.57 | 47.53 |
| 2 | 65.80 | 57.67 | 53.13 | 64.70 | 56.63 | 52.53 | 61.43 | 53.07 | 49.50 | 59.87 | 53.20 | 50.87 | 56.17 | 50.17 | 48.30 |
| 3 | 66.97 | 60.23 | 55.37 | 65.57 | 59.13 | 54.63 | 63.43 | 55.63 | 51.40 | 62.50 | 55.50 | 53.17 | 58.90 | 52.13 | 49.53 |
| 5 | 67.63 | 62.53 | 58.13 | 66.70 | 61.50 | 57.23 | 65.13 | 58.80 | 54.37 | 64.63 | 59.03 | 56.17 | 62.00 | 55.67 | 52.37 |
| 6 | 64.50 | 60.97 | 58.03 | 64.30 | 60.13 | 57.17 | 63.77 | 59.20 | 55.27 | 62.93 | 59.17 | 56.87 | 62.33 | 57.03 | 53.70 |
| 7 | 61.03 | 57.57 | 56.47 | 60.57 | 58.97 | 56.00 | 59.43 | 57.73 | 55.40 | 58.13 | 57.33 | 56.37 | 59.53 | 57.60 | 54.73 |
| 8 | 60.07 | 57.10 | 56.00 | 59.57 | 56.50 | 55.47 | 58.13 | 56.90 | 54.80 | 57.07 | 56.30 | 55.47 | 58.17 | 57.17 | 55.03 |
| 10 | 56.33 | 54.57 | 54.67 | 55.73 | 54.03 | 54.33 | 54.13 | 54.93 | 54.47 | 53.10 | 54.07 | 54.63 | 54.57 | 56.40 | 55.53 |
| 12 | 57.33 | 55.70 | 55.30 | 56.53 | 55.10 | 54.47 | 56.27 | 55.53 | 53.90 | 55.00 | 54.70 | 54.07 | 54.43 | 54.50 | 54.13 |
| 13 | 60.73 | 57.03 | 55.70 | 59.97 | 55.77 | 54.60 | 59.03 | 55.80 | 53.73 | 58.23 | 55.23 | 54.03 | 55.80 | 54.17 | 53.77 |
| 14 | 58.17 | 56.60 | 56.10 | 58.73 | 56.37 | 55.17 | 57.73 | 56.67 | 54.30 | 57.23 | 56.20 | 54.83 | 56.83 | 54.83 | 53.73 |
| 15 | 59.73 | 56.40 | 55.40 | 60.43 | 56.47 | 54.90 | 58.07 | 55.77 | 54.10 | 58.53 | 55.73 | 54.67 | 57.43 | 55.03 | 54.10 |
| 16 | 59.57 | 57.43 | 56.67 | 60.50 | 57.70 | 56.03 | 58.80 | 57.03 | 54.57 | 58.77 | 56.97 | 55.47 | 58.83 | 56.00 | 54.47 |
| 17 | 60.73 | 57.70 | 56.73 | 61.23 | 57.97 | 56.33 | 58.70 | 57.00 | 54.77 | 58.83 | 56.83 | 55.60 | 58.73 | 56.40 | 54.97 |
| 19 | 62.37 | 58.33 | 57.13 | 61.90 | 57.97 | 56.37 | 59.57 | 56.80 | 55.03 | 57.77 | 55.93 | 55.37 | 58.13 | 56.57 | 55.43 |
| 20 | 60.87 | 59.63 | 58.70 | 60.27 | 59.03 | 57.67 | 59.83 | 58.57 | 55.80 | 57.73 | 57.50 | 56.17 | 58.97 | 56.90 | 55.50 |
| 21 | 61.27 | 58.57 | 57.53 | 61.10 | 58.20 | 56.63 | 59.70 | 57.47 | 55.57 | 58.77 | 56.53 | 55.70 | 58.23 | 56.63 | 55.57 |
| 22 | 58.87 | 58.73 | 58.33 | 58.07 | 58.40 | 57.50 | 59.17 | 58.63 | 56.03 | 58.57 | 58.27 | 56.73 | 59.87 | 57.23 | 55.77 |
| 23 | 55.83 | 55.77 | 55.80 | 55.60 | 55.40 | 55.47 | 55.73 | 56.33 | 55.57 | 55.30 | 55.87 | 55.80 | 57.23 | 56.97 | 56.03 |
| 24 | 61.90 | 57.57 | 56.10 | 62.43 | 57.37 | 55.40 | 59.63 | 56.10 | 54.67 | 59.00 | 55.90 | 55.00 | 58.27 | 56.37 | 55.73 |
| 26 | 51.83 | 53.33 | 54.33 | 51.10 | 52.87 | 54.37 | 52.20 | 54.97 | 54.97 | 51.60 | 54.00 | 55.00 | 54.53 | 56.37 | 55.70 |
| 27 | 58.97 | 54.90 | 53.90 | 59.70 | 55.03 | 53.07 | 58.83 | 53.97 | 53.43 | 56.57 | 53.70 | 53.53 | 55.50 | 54.97 | 55.17 |
| 28 | 64.77 | 59.03 | 57.00 | 64.90 | 59.03 | 56.13 | 61.50 | 56.47 | 54.07 | 60.77 | 56.23 | 54.67 | 58.73 | 55.37 | 54.70 |
| 29 | 64.47 | 61.83 | 60.37 | 63.97 | 61.30 | 58.87 | 63.17 | 59.93 | 56.13 | 62.07 | 59.37 | 57.03 | 61.40 | 57.07 | 55.13 |
| 30 | 60.03 | 58.97 | 58.57 | 59.43 | 58.37 | 57.67 | 59.90 | 58.93 | 56.90 | 59.70 | 58.43 | 57.43 | 59.90 | 57.73 | 56.00 |
| 31 | 64.37 | 60.30 | 59.03 | 65.17 | 60.27 | 58.00 | 62.60 | 59.20 | 56.83 | 62.40 | 59.13 | 57.43 | 61.33 | 57.93 | 56.53 |
| **Average** | **61.01** | **57.80** | **56.35** | **60.75** | **57.43** | **55.65** | **59.36** | **56.61** | **54.36** | **58.51** | **56.22** | **55.03** | **58.03** | **55.61** | **54.20** |

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TABLE 7.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND. JUNE, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 | 70.17 | 65.17 | 62.83 | 69.70 | 64.40 | 61.40 | 67.13 | 62.53 | 58.83 | 65.03 | 61.73 | 59.67 | 64.10 | 60.07 | 57.50 |
| 3 | 72.50 | 67.17 | 64.77 | 71.73 | 66.27 | 62.83 | 69.83 | 64.57 | 60.23 | 67.90 | 63.63 | 61.00 | 65.97 | 61.17 | 58.53 |
| 4 | 70.70 | 66.40 | 64.87 | 69.60 | 65.43 | 63.03 | 68.80 | 64.97 | 61.50 | 66.63 | 63.80 | 61.93 | 65.53 | 62.17 | 60.43 |
| 5 | 71.30 | 66.73 | 65.07 | 70.03 | 65.63 | 63.27 | 67.47 | 65.43 | 62.03 | 67.47 | 64.17 | 62.33 | 65.70 | 62.60 | 61.20 |
| 6 | 74.77 | 69.07 | 66.73 | 73.70 | 68.07 | 64.60 | 72.53 | 66.90 | 62.63 | 71.50 | 66.10 | 63.13 | 67.93 | 63.27 | 61.70 |
| 7 | 64.27 | 65.70 | 65.93 | 63.13 | 64.70 | 64.57 | 65.73 | 67.07 | 63.73 | 64.67 | 66.00 | 64.47 | 66.67 | 64.40 | 62.47 |
| 9 | 62.83 | 60.27 | 60.03 | 61.93 | 59.47 | 59.33 | 61.73 | 60.93 | 60.07 | 60.43 | 57.77 | 60.10 | 60.30 | 61.60 | 61.50 |
| 10 | 68.57 | 62.10 | 60.93 | 65.67 | 61.30 | 59.90 | 64.70 | 61.37 | 59.63 | 63.40 | 60.23 | 59.53 | 61.27 | 60.80 | 60.47 |
| 11 | 69.23 | 64.67 | 63.07 | 67.97 | 63.73 | 61.70 | 62.23 | 63.13 | 60.40 | 66.00 | 62.33 | 60.73 | 63.27 | 60.97 | 59.90 |
| 12 | 70.97 | 69.50 | 64.50 | 69.07 | 64.97 | 62.80 | 68.90 | 64.57 | 61.47 | 67.80 | 63.80 | 61.80 | 64.37 | 61.57 | 60.17 |
| 13 | 73.23 | 67.87 | 65.90 | 71.73 | 66.67 | 63.97 | 71.03 | 66.00 | 62.53 | 70.23 | 65.33 | 63.03 | 65.90 | 62.40 | 60.70 |
| 14 | 76.37 | 70.00 | 67.63 | 74.40 | 68.60 | 65.30 | 73.87 | 67.73 | 63.53 | 73.10 | 67.27 | 64.40 | 67.80 | 63.43 | 61.40 |
| 16 | 82.97 | 76.13 | 72.57 | 79.70 | 73.80 | 69.33 | 80.17 | 72.63 | 66.93 | 79.70 | 72.53 | 68.27 | 73.27 | 66.90 | 63.87 |
| 17 | 81.03 | 75.90 | 73.63 | 80.47 | 74.67 | 70.57 | 79.80 | 74.17 | 68.60 | 78.77 | 73.90 | 69.97 | 75.27 | 68.90 | 65.37 |
| 18 | 79.60 | 75.07 | 73.20 | 78.87 | 74.00 | 70.73 | 78.63 | 74.03 | 69.30 | 76.93 | 72.97 | 70.27 | 75.00 | 70.17 | 66.83 |
| 19 | 79.07 | 75.33 | 73.73 | 77.97 | 74.27 | 71.23 | 78.37 | 74.60 | 69.87 | 76.83 | 73.47 | 70.53 | 75.50 | 71.03 | 67.73 |
| 20 | 75.00 | 73.17 | 72.27 | 74.20 | 72.10 | 70.30 | 75.47 | 73.63 | 69.93 | 74.50 | 72.53 | 70.37 | 74.53 | 71.43 | 68.50 |
| 21 | 70.77 | 70.17 | 69.87 | 70.67 | 69.17 | 68.43 | 71.67 | 71.30 | 68.97 | 71.07 | 70.37 | 69.30 | 72.23 | 71.00 | 68.73 |
| 23 | 76.70 | 71.50 | 69.70 | 76.60 | 70.93 | 68.37 | 74.57 | 70.23 | 67.27 | 72.80 | 69.17 | 67.53 | 71.80 | 69.40 | 67.80 |
| 24 | 78.90 | 73.90 | 71.83 | 77.13 | 73.07 | 70.07 | 77.00 | 72.07 | 68.33 | 75.23 | 70.90 | 68.67 | 73.50 | 69.80 | 68.03 |
| 25 | 81.53 | 76.27 | 73.93 | 79.90 | 75.27 | 71.77 | 79.80 | 74.20 | 69.47 | 78.37 | 73.30 | 70.07 | 75.83 | 70.80 | 68.47 |
| 26 | 82.80 | 77.33 | 75.17 | 80.83 | 78.40 | 72.83 | 81.07 | 75.47 | 70.87 | 79.80 | 74.73 | 71.40 | 77.23 | 72.03 | 68.90 |
| 27 | 85.47 | 79.73 | 77.07 | 83.77 | 78.40 | 74.30 | 83.63 | 77.27 | 71.87 | 82.37 | 76.63 | 72.83 | 79.03 | 73.43 | 69.93 |
| 28 | 87.83 | 81.30 | 78.70 | 85.03 | 79.87 | 75.67 | 85.83 | 79.00 | 73.37 | 84.40 | 78.33 | 73.87 | 80.37 | 74.73 | 70.97 |
| 30 | 86.33 | 81.87 | 79.00 | 83.93 | 80.07 | 77.10 | 85.10 | 80.60 | 75.67 | 83.47 | 79.47 | 76.37 | 81.07 | 77.23 | 73.43 |
| Average | 75.72 | 71.29 | 69.32 | 74.30 | 70.13 | 67.34 | 73.80 | 69.78 | 65.88 | 72.74 | 68.82 | 66.46 | 70.54 | 66.85 | 64.58 |



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TABLE 8.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JULY, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 84.23 | 80.47 | 78.87 | 82.60 | 79.00 | 76.69 | 83.67 | 80.03 | 75.70 | 82 07 | 78 53 | 76.30 | 80.63 | 77.57 | 74.17 |
| 2 | 81.50 | 80.20 | 78 23 | 82.27 | 78.83 | 76.03 | 83.67 | 79.33 | 75.27 | 81.77 | 78.13 | 75.57 | 79.93 | 77.17 | 74.23 |
| 3 | 83.00 | 81.33 | 79.20 | 83.27 | 79.33 | 76.70 | 84 80 | 80.00 | 75.63 | 83.23 | 78.83 | 76.07 | 80.37 | 77.37 | 74.50 |
| 4 | 86.10 | 82.63 | 80.70 | 83 23 | 81.07 | 77.97 | 85.83 | 81.37 | 76.43 | 84.07 | 80.37 | 77.03 | 81.83 | 77.83 | 74 60 |
| 5 | 79.33 | 78.50 | 78.23 | 77.50 | 77.43 | 76.40 | 79.90 | 79.67 | 76.43 | 79.10 | 78.57 | 76.83 | 79.47 | 77.97 | 75 07 |
| 7 | 73.60 | 70.87 | 71.00 | 72.13 | 69.70 | 70 43 | 72.27 | 72.33 | 72.13 | 70.43 | 70.67 | 71.63 | 71.40 | 74.27 | 73.77 |
| 8 | 74.03 | 72.27 | 71.93 | 72.67 | 71.43 | 70.87 | 73.60 | 72.63 | 70.90 | 71.63 | 71.03 | 70.67 | 72.03 | 72.63 | 72.17 |
| 9 | 77.30 | 72.87 | 71.70 | 76.10 | 72.27 | 70.63 | 75.53 | 72.30 | 70.40 | 74.20 | 71.13 | 70.30 | 72.90 | 71.90 | 71.07 |
| 10 | 76.70 | 73.30 | 72.40 | 73.37 | 72 43 | 71 30 | 75.53 | 72.93 | 70.73 | 73.60 | 71.50 | 70 73 | 72.83 | 71.90 | 70.63 |
| 11 | 76.80 | 73.60 | 72.60 | 75.00 | 72.53 | 71.47 | 75.77 | 73.40 | 70.90 | 73.83 | 71.87 | 71.27 | 72.67 | 71.83 | 70.47 |
| 12 | 77.53 | 74.70 | 73.60 | 76.13 | 74.03 | 72.33 | 76.70 | 74 20 | 71.30 | 75.13 | 72 93 | 71.47 | 73.97 | 71.93 | 70.47 |
| 14 | 79.63 | 75.70 | 73.80 | 77.97 | 74.67 | 72.70 | 77.80 | 74.40 | 71.57 | 76.33 | 73.27 | 71.80 | 73.90 | 72.20 | 70.67 |
| 15 | 80.53 | 76 57 | 75.33 | 78.03 | 75.67 | 73.60 | 79.10 | 75.57 | 72.17 | 77.77 | 74.53 | 72.63 | 75.60 | 72.77 | 70.87 |
| 16 | 80.50 | 77.30 | 76.10 | 78.03 | 76.43 | 74.40 | 79.43 | 76.27 | 72.97 | 77.93 | 75.27 | 73.37 | 76.27 | 73.70 | 71.37 |
| 17 | 75.50 | 74.70 | 74.67 | 74.20 | 73.77 | 73.73 | 75.63 | 75.57 | 73.30 | 75.37 | 74.63 | 73.47 | 74.37 | 73.83 | 71.97 |
| 18 | 78.87 | 74.90 | 73.73 | 79.87 | 75.03 | 72.90 | 77.20 | 74.33 | 72.17 | 76.33 | 73.73 | 72.53 | 75.63 | 73.73 | 72.03 |
| 19 | 79.43 | 75.70 | 74.50 | 79 10 | 75.53 | 73.73 | 77.17 | 74.67 | 72.13 | 75.63 | 73.70 | 72.60 | 74.70 | 73.83 | 72.07 |
| 21 | 77.70 | 74.37 | 73.63 | 76.13 | 73.47 | 72.50 | 75.90 | 73.90 | 72.00 | 74.10 | 72.50 | 71.97 | 73.27 | 72.77 | 71.67 |
| 22 | 76.80 | 74.17 | 73.73 | 74.43 | 72 83 | 72 43 | 75.03 | 73.80 | 72.00 | 73 20 | 72.27 | 71.83 | 72.70 | 72.53 | 71.37 |
| 23 | 71.50 | 72.63 | 73.10 | 70.00 | 71 67 | 72.13 | 71.93 | 73.47 | 71.63 | 70.33 | 71.87 | 71.53 | 71.87 | 72.23 | 71.03 |
| 24 | 72.27 | 70.20 | 70.10 | 71.33 | 69.50 | 69.47 | 71.50 | 70.57 | 70.07 | 70.47 | 69.43 | 69.80 | 70.47 | 70.90 | 70.57 |
| 25 | 73.77 | 70.53 | 69.97 | 72.03 | 69.50 | 69.73 | 72.30 | 70.47 | 69.40 | 70.87 | 69.27 | 69.30 | 70.30 | 70.40 | 70.00 |
| 26 | 78.97 | 74.03 | 72.50 | 76.73 | 71.97 | 71.07 | 76.80 | 72.23 | 69.73 | 75.60 | 71.43 | 69.87 | 73.10 | 70.53 | 69.57 |
| 28 | 80.30 | 76.50 | 75.07 | 78.93 | 75.97 | 73.43 | 78.97 | 75.33 | 72.07 | 78.30 | 74.80 | 72.77 | 77.10 | 73.00 | 70.63 |
| 29 | 81.63 | 77.47 | 76.03 | 80.40 | 77.00 | 74.53 | 79.73 | 76.17 | 72.87 | 78.73 | 75.53 | 73.57 | 77.97 | 74.33 | 71.63 |
| 30 | 85.37 | 80.13 | 78.13 | 83.57 | 79.30 | 75.97 | 85.67 | 77.80 | 73.90 | 81.93 | 77.23 | 74.57 | 80.07 | 75.43 | 72.60 |
| 31 | 82.70 | 80.23 | 79.13 | 80.07 | 79.10 | 77.07 | 81.63 | 79.07 | 75.03 | 80.33 | 78.13 | 75.93 | 79.70 | 76.73 | 73.63 |
| Average | 78.73 | 75.77 | 74.74 | 77.23 | 74.79 | 73.34 | 77.89 | 75.25 | 72.55 | 76.38 | 74.11 | 72.79 | 75.34 | 73.75 | 71.96 |

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TABLE 9.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, AUGUST, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 79.17 | 76.83 | 76.40 | 78.03 | 76.00 | 74.90 | 78.63 | 77 03 | 74.90 | 77.40 | 76.03 | 75.10 | 77.90 | 76.40 | 74.07 |
| 2 | 80.60 | 76.50 | 75.60 | 77.87 | 75.80 | 74.37 | 79.23 | 76.50 | 74.17 | 77.73 | 75.13 | 74.23 | 77.57 | 76.10 | 74.17 |
| 4 | 77.20 | 74.27 | 73.93 | 76.17 | 73.57 | 72.93 | 76.27 | 74.73 | 73.33 | 76.47 | 73.30 | 73.17 | 75.23 | 75.03 | 73.83 |
| 5 | 75.97 | 73.70 | 73.47 | 74.40 | 72.80 | 72.50 | 75.00 | 74.13 | 72.67 | 73.33 | 72.57 | 72.57 | 73.73 | 74.40 | 73.30 |
| 6 | 75.97 | 74.30 | 73.97 | 74.57 | 73.40 | 72.90 | 75.23 | 74.37 | 72.40 | 73.73 | 72.93 | 72.33 | 73.90 | 73.77 | 72.63 |
| 7 | 77.60 | 73.63 | 73.10 | 76.60 | 73.23 | 72.13 | 76.10 | 73.50 | 71.87 | 75.07 | 72.43 | 71.83 | 73.97 | 73.20 | 72.27 |
| 8 | 79.00 | 75.90 | 74.90 | 78.43 | 75.43 | 73.73 | 77.87 | 75.10 | 72.37 | 77.00 | 74.23 | 72.70 | 76.17 | 73.83 | 72.13 |
| 9 | 77.33 | 75.30 | 74.93 | 76.87 | 75.20 | 74.40 | 76.77 | 75.37 | 73.17 | 76.43 | 74.57 | 73.33 | 75.70 | 74.77 | 72.93 |
| 11 | 69.73 | 69.27 | 70.17 | 70.73 | 69.57 | 70.57 | 69.47 | 71.23 | 71.70 | 69.00 | 70.13 | 71.20 | 71.50 | 74.43 | 74.30 |
| 12 | 72.63 | 70.33 | 70.07 | 73.10 | 71.00 | 70.40 | 71.40 | 70.37 | 69.97 | 70.53 | 69.50 | 69.83 | 71:57 | 72.77 | 72.87 |
| 13 | 78.07 | 73.23 | 71.97 | 78.07 | 73.37 | 71.40 | 75.40 | 71.53 | 69.80 | 74.57 | 71.03 | 70.03 | 72.97 | 72.07 | 71.53 |
| 14 | 80.80 | 76.40 | 74.80 | 80.60 | 76.10 | 73.60 | 78.63 | 74.13 | 71.00 | 77.73 | 73.73 | 71.63 | 75.77 | 72.53 | 71.10 |
| 15 | 82.80 | 78.07 | 76.47 | 82.00 | 77.57 | 74.87 | 80.67 | 76.03 | 72.50 | 79.93 | 75.73 | 73.43 | 78.23 | 73.93 | 71.67 |
| 16 | 84.07 | 80.43 | 78.50 | 82.43 | 79.80 | 76.53 | 83.07 | 78.47 | 74.17 | 82.03 | 77.83 | 74.90 | 81.03 | 75.57 | 72.70 |
| 18 | 78.97 | 76.30 | 75.60 | 79.43 | 76.10 | 74.57 | 78.67 | 76.43 | 74.43 | 78.33 | 75.70 | 74.53 | 78.07 | 76.90 | 75.27 |
| 19 | 77.60 | 75.27 | 74.80 | 78.47 | 75.67 | 74.43 | 77.03 | 75.70 | 73.83 | 75.93 | 74.83 | 74.13 | 77.27 | 76.60 | 75.03 |
| 20 | 76.83 | 74.47 | 74.17 | 77.40 | 74.40 | 73.83 | 75.37 | 74.60 | 73.23 | 74.20 | 73.43 | 73.23 | 75.33 | 75.60 | 74.50 |
| 21 | 75.67 | 74.90 | 74.60 | 74.80 | 74.67 | 73.93 | 75.53 | 74.83 | 73.10 | 74.77 | 73.90 | 73.20 | 76.07 | 75.03 | 73.80 |
| 22 | 74.37 | 73.63 | 73.60 | 74.43 | 73.67 | 73.03 | 74.60 | 74.07 | 72.40 | 74.13 | 73.47 | 72.73 | 75.37 | 74.50 | 73.37 |
| 23 | 72.23 | 70.90 | 71.07 | 72.53 | 71.27 | 71.33 | 71.47 | 71.70 | 71.40 | 70.83 | 70.90 | 71.43 | 71.93 | 73.43 | 73.00 |
| 25 | 70.17 | 69.47 | 70.03 | 69.47 | 69.10 | 69.90 | 69.23 | 70.13 | 69.90 | 68.30 | 69.13 | 69.90 | 68.67 | 70.90 | 71.00 |
| 26 | 76.33 | 71.83 | 70.77 | 76.00 | 71.83 | 70.20 | 73.90 | 70.40 | 69.17 | 73.03 | 69.90 | 69.30 | 71.40 | 70.03 | 70.07 |
| 27 | 75.90 | 72.43 | 71.63 | 75.10 | 71.90 | 70.90 | 74.17 | 71.30 | 69.67 | 73.10 | 70.63 | 70.10 | 71.70 | 70.43 | 69.67 |
| 28 | 71.20 | 71.07 | 71.33 | 70.00 | 70.53 | 70.70 | 70.67 | 71.30 | 70.00 | 69.80 | 70.37 | 70.20 | 71.07 | 70.67 | 69.70 |
| 29 | 69.87 | 68.67 | 69.03 | 69.00 | 68.23 | 68.90 | 68.97 | 69.27 | 69.07 | 68.27 | 68.33 | 69.03 | 69.00 | 69.93 | 69.63 |
| 30 | 70.97 | 69.17 | 69.03 | 70.07 | 68.87 | 68.73 | 69.83 | 68.93 | 68.37 | 69.07 | 68.20 | 68.43 | 69.20 | 69.33 | 69.27 |
| Average | 76.19 | 73.70 | 73.23 | 75.64 | 73.43 | 72.53 | 75.12 | 73.50 | 71.87 | 74.26 | 72.61 | 72.02 | 74.24 | 73.54 | 72.45 |

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TABLE 10.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, SEPTEMBER, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 72.73 | 70.40 | 69.90 | 72.17 | 70.07 | 69.30 | 71.47 | 69.77 | 68.37 | 71.03 | 69.27 | 68.63 | 70.07 | 69.27 | 68.47 |
| 2 | 77.57 | 72.60 | 71.10 | 76.83 | 72.10 | 70.10 | 75.00 | 70.63 | 68.67 | 74.57 | 70.27 | 69.13 | 72.13 | 69.70 | 68.90 |
| 3 | 79.10 | 75.40 | 74.00 | 77.90 | 74.87 | 72.47 | 77.63 | 73.80 | 70.07 | 76.80 | 73.03 | 71.00 | 75.30 | 71.17 | 69.10 |
| 4 | 75.20 | 73.83 | 73.57 | 74.20 | 73.30 | 72.43 | 74.37 | 73.53 | 71.03 | 73.50 | 72.83 | 71.77 | 74.47 | 72.27 | 70.20 |
| 5 | 75.70 | 72.27 | 71.60 | 75.03 | 71.63 | 70.77 | 73.93 | 71.83 | 70.53 | 73.37 | 71.00 | 70.77 | 73.00 | 71.83 | 70.60 |
| 6 | 75.83 | 73.20 | 72.40 | 74.93 | 72.37 | 71.20 | 74.70 | 72.47 | 70.40 | 73.80 | 71.40 | 70.77 | 73.43 | 71.77 | 70.43 |
| 8 | 73.10 | 72.90 | 72.90 | 72.43 | 72.23 | 71.87 | 73.40 | 73.30 | 71.37 | 72.87 | 72.27 | 71.80 | 74.13 | 72.70 | 71.07 |
| 9 | 69.40 | 68.40 | 69.20 | 68.57 | 67.80 | 68.90 | 68.70 | 69.83 | 70.13 | 67.87 | 68.47 | 70.00 | 69.43 | 71.60 | 70.97 |
| 10 | 68.20 | 67.03 | 67.60 | 67.40 | 66.47 | 67.67 | 67.17 | 68.10 | 68.60 | 66.17 | 66.63 | 68.27 | 67.70 | 70.00 | 70.10 |
| 11 | 69.70 | 67.43 | 67.50 | 68.93 | 67.00 | 67.37 | 68.00 | 67.53 | 67.53 | 67.13 | 66.17 | 67.37 | 67.60 | 68.87 | 69.20 |
| 12 | 70.00 | 68.53 | 68.47 | 69.13 | 68.23 | 68.30 | 69.03 | 68.37 | 67.40 | 68.13 | 67.33 | 67.53 | 69.03 | 68.53 | 68.13 |
| 13 | 65.57 | 66.03 | 66.80 | 64.93 | 65.73 | 66.90 | 65.43 | 66.87 | 67.03 | 64.30 | 65.70 | 66.90 | 66.53 | 67.97 | 68.00 |
| 15 | 63.87 | 63.40 | 64.13 | 62.90 | 63.07 | 64.47 | 62.97 | 64.20 | 64.97 | 62.07 | 62.93 | 64.63 | 63.20 | 65.67 | 66.47 |
| 16 | 63.53 | 64.20 | 64.90 | 63.17 | 64.07 | 64.97 | 63.57 | 64.70 | 64.57 | 63.23 | 63.83 | 64.57 | 64.23 | 65.20 | 65.43 |
| 17 | 65.83 | 64.73 | 64.73 | 65.33 | 64.67 | 64.73 | 65.03 | 64.63 | 64.17 | 65.23 | 64.13 | 64.40 | 65.10 | 64.80 | 64.97 |
| 18 | 61.37 | 62.57 | 63.33 | 60.83 | 62.40 | 63.70 | 61.87 | 63.60 | 64.03 | 61.87 | 62.87 | 64.17 | 62.73 | 64.57 | 64.67 |
| 19 | 62.00 | 61.03 | 61.83 | 61.20 | 60.87 | 62.20 | 61.13 | 62.03 | 62.90 | 61.50 | 61.33 | 62.90 | 60.93 | 63.53 | 64.17 |
| 20 | 62.43 | 62.13 | 62.57 | 62.20 | 62.07 | 62.73 | 62.03 | 62.47 | 62.53 | 62.00 | 61.90 | 62.73 | 62.30 | 63.17 | 63.57 |
| 22 | 53.97 | 55.47 | 57.20 | 53.40 | 55.30 | 58.27 | 53.67 | 57.47 | 60.10 | 53.90 | 56.57 | 59.60 | 55.63 | 60.70 | 62.73 |
| 23 | 54.43 | 54.50 | 55.53 | 54.37 | 54.43 | 56.80 | 53.37 | 55.60 | 58.13 | 53.33 | 54.87 | 57.63 | 53.80 | 58.67 | 61.47 |
| 24 | 60.93 | 58.00 | 57.63 | 62.13 | 58.67 | 58.40 | 58.63 | 56.90 | 57.60 | 58.97 | 56.73 | 57.60 | 56.77 | 57.73 | 59.90 |
| 25 | 64.30 | 61.43 | 60.83 | 64.63 | 61.60 | 61.00 | 61.77 | 59.60 | 58.90 | 62.00 | 59.60 | 59.47 | 59.40 | 58.53 | 59.53 |
| 26 | 60.93 | 62.13 | 62.47 | 60.07 | 61.97 | 62.40 | 60.77 | 61.57 | 60.47 | 60.60 | 61.23 | 61.30 | 60.80 | 59.73 | 59.83 |
| 27 | 58.40 | 57.77 | 58.70 | 58.47 | 57.50 | 59.27 | 56.90 | 58.37 | 59.93 | 56.77 | 57.60 | 59.83 | 56.70 | 59.37 | 60.30 |
| 29 | 62.23 | 61.03 | 60.80 | 62.13 | 61.07 | 60.80 | 61.17 | 60.07 | 59.43 | 61.13 | 59.63 | 59.63 | 60.07 | 59.03 | 59.83 |
| 30 | 64.90 | 62.77 | 62.10 | 65.03 | 62.80 | 61.77 | 63.63 | 61.47 | 60.20 | 63.67 | 60.93 | 60.63 | 62.43 | 59.87 | 59.97 |
| Average | 66.59 | 65.35 | 65.45 | 66.09 | 65.09 | 65.34 | 65.59 | 65.34 | 64.96 | 65.22 | 64.56 | 65.12 | 65.27 | 65.63 | 65.69 |

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TABLE 11.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, OCTOBER, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12 | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 64.07 | 62.97 | 62.87 | 63.53 | 62.90 | 62.53 | 63.87 | 62.07 | 61.73 | 63.80 | 61.50 | 61.87 | 63.03 | 61.23 | 60.77 |
| 2 | 58.07 | 60.47 | 61.60 | 57.10 | 60.00 | 61.73 | 58.93 | 61.67 | 61.60 | 58.93 | 60.77 | 61.93 | 60.73 | 61.67 | 61.47 |
| 3 | 59.33 | 58.60 | 59.07 | 59.07 | 58.40 | 59.40 | 58.53 | 59.23 | 60.13 | 58.70 | 58.50 | 60.10 | 59.00 | 60.50 | 61.37 |
| 4 | 59.13 | 58.30 | 58.73 | 59.03 | 58.00 | 58.97 | 57.93 | 58.60 | 59.40 | 57.87 | 57.67 | 59.33 | 57.70 | 59.90 | 60.93 |
| 6 | 63.90 | 61.30 | 60.87 | 64.13 | 61.27 | 60.73 | 61.90 | 60.33 | 59.57 | 62.03 | 59.40 | 60.00 | 60.63 | 59.73 | 60.13 |
| 7 | 69.83 | 63 77 | 62.87 | 66.57 | 63.60 | 62.43 | 64.43 | 62.10 | 60.57 | 64.50 | 61.33 | 61.33 | 63.17 | 60.73 | 60.40 |
| 8 | 66.13 | 64.93 | 64.40 | 65.73 | 64.73 | 63.83 | 65.43 | 63.73 | 61.87 | 65 57 | 63.37 | 62.60 | 64.93 | 62.00 | 61.20 |
| 9 | 65.63 | 64.17 | 63.93 | 65.30 | 63.87 | 63.40 | 64.93 | 63.70 | 62.40 | 64.93 | 63.20 | 63.03 | 64.47 | 62.73 | 61.93 |
| 10 | 66.63 | 64.93 | 64.40 | 67.13 | 64.90 | 63.90 | 66.00 | 64.27 | 62.70 | 65.97 | 63.57 | 63.30 | 65.43 | 63.27 | 62.53 |
| 11 | 62.90 | 64.23 | 64.57 | 61.93 | 64.07 | 64.43 | 63.17 | 64.73 | 63.57 | 63.17 | 63.27 | 63.83 | 64.87 | 64.07 | 63.07 |
| 13 | 52.17 | 53 60 | 55.47 | 51.43 | 53.27 | 56.67 | 52.23 | 55.87 | 58.93 | 52.03 | 54.03 | 58.27 | 53.67 | 59.90 | 62.00 |
| 14 | 53.87 | 53.50 | 54.43 | 54.47 | 53.73 | 55.80 | 52.67 | 54.53 | 56.63 | 52.83 | 52.70 | 56.10 | 53.10 | 57.37 | 59.10 |
| 15 | 55.80 | 55.23 | 56.07 | 56.10 | 55.57 | 56.63 | 54.63 | 55.13 | 56.10 | 54.63 | 53.60 | 56.03 | 54.27 | 56.40 | 58.10 |
| 16 | 54.73 | 55.60 | 56.43 | 54.63 | 55.83 | 57.13 | 54.10 | 55.80 | 56.37 | 54.33 | 54.37 | 56.43 | 54.90 | 56.37 | 56.93 |
| 17 | 55.67 | 55.50 | 56.07 | 55.47 | 55.63 | 56.67 | 55.00 | 55.53 | 56.13 | 55.33 | 54.00 | 56.23 | 54.97 | 55.97 | 57.93 |
| 18 | 51 70 | 54.13 | 55.47 | 50.63 | 54.00 | 56.27 | 52.20 | 55.37 | 56.37 | 52.33 | 54.10 | 56.50 | 54.13 | 56.20 | 57.43 |
| 20 | 45.83 | 48.20 | 50.10 | 45.37 | 48.17 | 51.40 | 45.80 | 49.97 | 53.00 | 46.03 | 48.47 | 52.50 | 48.03 | 52.97 | 55.80 |
| 21 | 46.37 | 47.77 | 49.23 | 46.17 | 47.87 | 50.53 | 45.50 | 48.80 | 51.53 | 45.67 | 47.33 | 51.17 | 47.13 | 51.57 | 54.70 |
| 22 | 42.90 | 45.93 | 47.97 | 42.10 | 45.87 | 49.47 | 42.73 | 47.47 | 50.53 | 43.27 | 46.17 | 50.13 | 45.53 | 50.43 | 53.47 |
| 23 | 40.20 | 43.43 | 45.73 | 39.53 | 43.13 | 47.30 | 40.23 | 44.97 | 48.67 | 40.83 | 43.73 | 48.27 | 42.53 | 48.73 | 52.37 |
| 24 | 45.00 | 44.87 | 45.33 | 44.77 | 44.63 | 46.27 | 43.50 | 45.07 | 47.10 | 44.07 | 42.57 | 46.87 | 42.10 | 46.43 | 50.30 |
| 25 | 43.50 | 44.97 | 46.17 | 42.73 | 44.87 | 47.23 | 43.00 | 45.33 | 47.40 | 43.40 | 44.37 | 47.33 | 42.87 | 45.97 | 49.17 |
| 27 | 44.43 | 46.00 | 47.00 | 44.10 | 46.17 | 48.00 | 44.23 | 46.20 | 47.53 | 44 60 | 44.83 | 47.57 | 44.23 | 45.57 | 48.47 |
| 28 | 44.40 | 45.33 | 46.30 | 43.87 | 45.43 | 47.47 | 43.60 | 45.47 | 47.20 | 44.20 | 43.33 | 47.43 | 43.80 | 45.97 | 48.37 |
| 29 | 44.37 | 45.37 | 46.37 | 43.83 | 45.43 | 47.33 | 43.80 | 45.63 | 47.20 | 44.37 | 43.83 | 47.27 | 43.70 | 45.83 | 48.20 |
| 30 | 41.00 | 43.63 | 45.27 | 39.67 | 43.37 | 46.50 | 40.70 | 44.53 | 46.83 | 41.47 | 43.53 | 46.83 | 42.30 | 45.63 | 48.07 |
| 31 | 40.00 | 42.10 | 43.77 | 39.90 | 41.87 | 44.93 | 39.73 | 43.17 | 45.77 | 40.07 | 41.80 | 45.73 | 40.47 | 44.70 | 47.70 |
| Average | 53.24 | 53.66 | 54.46 | 52.75 | 53.58 | 55.07 | 52.54 | 54.05 | 55.07 | 52.78 | 52.79 | 55.11 | 53.03 | 54.88 | 56.37 |

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TABLE 12.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, NOVEMBER, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 39.33 | 41.07 | 42.63 | 38.87 | 41.07 | 44.03 | 38.83 | 42.03 | 45.03 | 39.17 | 40.67 | 44.57 | 39.77 | 43.73 | 47 07 |
| 3 | 43.47 | 43.27 | 43.73 | 43.60 | 43.60 | 44.77 | 41.70 | 42.53 | 44.03 | 42.20 | 40.40 | 43.93 | 40.70 | 42.67 | 45.70 |
| 4 | 40.80 | 42.63 | 43.87 | 40.47 | 42.80 | 45.00 | 40.37 | 43.00 | 44.67 | 40.80 | 41.53 | 44.77 | 41.10 | 43.10 | 45.53 |
| 5 | 39.63 | 41.00 | 42.40 | 39.53 | 41.27 | 43.80 | 38.67 | 41.80 | 44.27 | 38.80 | 40.13 | 44.03 | 39.73 | 42.93 | 45.53 |
| 6 | 39.80 | 40.80 | 42.03 | 39.83 | 41.13 | 43.47 | 38.90 | 41.53 | 43.80 | 38.80 | 39.30 | 43.47 | 39.27 | 42.53 | 45.30 |
| 7 | 45.83 | 44.30 | 44.00 | 46.37 | 44.53 | 44.83 | 43.93 | 42.83 | 43.80 | 44.40 | 42.00 | 43.67 | 41.23 | 42.23 | 44.90 |
| 8 | 45.37 | 46.57 | 46.87 | 44.93 | 46.70 | 47.30 | 45.07 | 45.87 | 45.37 | 45.60 | 45.40 | 45.90 | 44.60 | 43.47 | 45.03 |
| 10 | 35.60 | 38.67 | 40.77 | 34.60 | 38.70 | 42.47 | 36.07 | 40.80 | 44.00 | 35.80 | 40.07 | 43.43 | 39.00 | 43.20 | 45.97 |
| 11 | 35.67 | 38.17 | 39.83 | 34.87 | 38.03 | 41.30 | 35.43 | 39.43 | 42.50 | 35.37 | 38.87 | 41.83 | 37.70 | 42.07 | 45.17 |
| 12 | 35.30 | 37.63 | 39.30 | 34.83 | 37.73 | 40.83 | 35.10 | 38.57 | 41.50 | 35.30 | 38.03 | 40.90 | 36.93 | 41.10 | 44.40 |
| 13 | 36.47 | 37.97 | 38.47 | 37.57 | 38.23 | 40.13 | 39.80 | 38.97 | 40.80 | 41.30 | 39.07 | 40.93 | 37.27 | 40.27 | 43.43 |
| 14 | 37.47 | 37.97 | 38.77 | 39.67 | 40.77 | 41.97 | 41.13 | 41.57 | 42.10 | 41.80 | 41.70 | 42.67 | 39.93 | 40.57 | 42.93 |
| 15 | 35.30 | 37.60 | 38.97 | 35.43 | 38.67 | 41.47 | 37.13 | 40.93 | 42.70 | 37.57 | 40.77 | 42.87 | 38.73 | 41.07 | 43.13 |
| 17 | 37.23 | 38.17 | 39.00 | 37.20 | 38 60 | 40.73 | 37.27 | 39 43 | 41.33 | 37.57 | 39.20 | 41.33 | 37.13 | 40.23 | 42.90 |
| 18 | 43.00 | 41.53 | 41.13 | 43.60 | 42.03 | 42.13 | 41.87 | 40.87 | 41.57 | 42.53 | 40.63 | 41.67 | 39.27 | 40.00 | 42.53 |
| 19 | 51.43 | 47.50 | 45.73 | 52.07 | 48.03 | 45.77 | 50.23 | 45.40 | 43.20 | 50.33 | 45 13 | 44.07 | 45.33 | 41.33 | 42.63 |
| 20 | 53.13 | 50.77 | 49.47 | 53.30 | 50.97 | 49.03 | 52.17 | 48.67 | 46.00 | 52.73 | 48.67 | 47.33 | 49.47 | 44.37 | 43.80 |
| 21 | 54.60 | 52.53 | 51.20 | 54.67 | 52.57 | 50.73 | 53.87 | 50.77 | 48.17 | 54.37 | 50.80 | 49.43 | 51.67 | 46.70 | 45.67 |
| 22 | 55.30 | 53.30 | 52.23 | 55.43 | 53.27 | 51.70 | 54.60 | 52.10 | 49.77 | 54.73 | 52.20 | 50.93 | 52.87 | 48.73 | 47.60 |
| 24 | 41.33 | 44.57 | 46.47 | 40.00 | 44.27 | 47.33 | 42.23 | 47.20 | 49.30 | 42.40 | 46.57 | 49.17 | 46.00 | 49.53 | 50.13 |
| 25 | 38.23 | 41.27 | 43.13 | 37.33 | 41.13 | 44.73 | 38.57 | 43.93 | 46.83 | 38.83 | 43.20 | 46.30 | 42.93 | 47.63 | 49.77 |
| 26 | 41.30 | 42.20 | 43.13 | 41.00 | 42.40 | 44.27 | 40.93 | 42.97 | 45.00 | 41.37 | 42.40 | 44.73 | 42.17 | 45.70 | 48.27 |
| 27 | 40.27 | 41.90 | 43.00 | 39.80 | 41.93 | 44.13 | 40.23 | 42.70 | 44.57 | 40.80 | 42.60 | 44.40 | 41.87 | 44.73 | 47.13 |
| 28 | 41.17 | 41.87 | 42.77 | 40.93 | 41.97 | 43.83 | 40.60 | 42.40 | 44.00 | 41.33 | 42.30 | 43.97 | 41.57 | 43.97 | 46.20 |
| 29 | 43.47 | 43.53 | 43.87 | 43.27 | 43.67 | 44.67 | 42.80 | 43.27 | 44.00 | 43.43 | 43.40 | 44.27 | 42.57 | 43.67 | 45.57 |
| Average | 42.02 | 42.67 | 43.71 | 41.97 | 42.96 | 44.42 | 41.90 | 43.18 | 44.33 | 42.29 | 42.60 | 44.42 | 41.95 | 43.42 | 45.45 |

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BEGINNING WITH THIRD YEAR.

TABLE 13.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. DECEMBER, 1913.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 50.60 | 49.33 | 48.53 | 50.50 | 49.47 | 48.40 | 49.73 | 47.73 | 46.23 | 50.27 | 48.07 | 47.00 | 47.73 | 45.20 | 45.77 |
| 2 | 50.80 | 49.80 | 49.30 | 50.77 | 49.57 | 49.23 | 50.23 | 48.80 | 47.50 | 50.73 | 49.10 | 48.27 | 49.03 | 46.63 | 46.57 |
| 3 | 47.33 | 48.63 | 49.00 | 46.73 | 48.47 | 49.17 | 47.80 | 48.93 | 48.37 | 48.17 | 48.97 | 48.93 | 48.57 | 47.70 | 47.67 |
| 4 | 43.87 | 44.67 | 45.90 | 42.47 | 44.43 | 46.63 | 43.13 | 46.47 | 47.57 | 43.63 | 46.47 | 47.63 | 45.20 | 47.47 | 48.33 |
| 5 | 41.80 | 43.57 | 44.70 | 41.30 | 43.50 | 45.60 | 41.83 | 44.60 | 46.37 | 42.03 | 44.27 | 46.27 | 43.67 | 46.47 | 48.20 |
| 6 | 40.87 | 42.37 | 43.70 | 40.17 | 42.27 | 44.73 | 40.53 | 43.47 | 45.40 | 40.83 | 43.07 | 45.13 | 42.07 | 45.47 | 47.53 |
| 8 | 34.67 | 38.37 | 40.67 | 34.63 | 38.97 | 42.57 | 36.10 | 40.93 | 43.90 | 36.03 | 40.43 | 43.40 | 39.93 | 43.93 | 46.80 |
| 9 | 33.20 | 36.70 | 38.83 | 33.00 | 37.20 | 41.00 | 34.57 | 39.17 | 42.33 | 34.20 | 38.53 | 41.57 | 37.53 | 42.43 | 45.40 |
| 10 | 33.53 | 36.30 | 38.00 | 33.40 | 36.80 | 40.10 | 34.20 | 38.17 | 41.17 | 34.17 | 37.37 | 40.37 | 36.50 | 41.13 | 44.40 |
| 11 | 33.33 | 36.13 | 37.67 | 33.10 | 36.60 | 39.70 | 33.90 | 37.57 | 40.50 | 34.07 | 37.07 | 39.80 | 36.17 | 40.13 | 43.20 |
| 12 | 33.23 | 35.97 | 37.23 | 33.00 | 36.10 | 39.10 | 33.53 | 36.97 | 39.77 | 33.63 | 36.50 | 39.10 | 35.50 | 39.23 | 42.27 |
| 13 | 34.93 | 36.27 | 37.30 | 34.90 | 36.80 | 39.03 | 33.53 | 36.77 | 39.30 | 34.03 | 36.43 | 38.80 | 34.87 | 38.60 | 41.63 |
| 15 | 33.87 | 36.27 | 37.63 | 33.30 | 36.47 | 39.17 | 34.13 | 37.10 | 39.23 | 34.67 | 37.00 | 38.99 | 34.33 | 37.87 | 40.70 |
| 16 | 36.60 | 37.03 | 37.67 | 36.40 | 37.27 | 39.00 | 35.17 | 36.93 | 38.93 | 35.83 | 36.87 | 38.73 | 33.87 | 37.57 | 40.37 |
| 17 | 35.50 | 37.13 | 38.07 | 35.00 | 37.40 | 39.40 | 35.17 | 37.40 | 39.13 | 36.30 | 37.53 | 39.10 | 34.30 | 37.43 | 40.13 |
| 18 | 34.30 | 36.43 | 37.67 | 33.67 | 36.53 | 38.90 | 34.43 | 37.27 | 39.17 | 35.00 | 37.33 | 39.03 | 34.57 | 37.30 | 39.93 |
| 19 | 33.23 | 35.57 | 36.90 | 32.47 | 35.63 | 38.40 | 33.67 | 36.77 | 38.77 | 34.10 | 36.70 | 38.63 | 34.10 | 37.20 | 39.90 |
| 20 | 33.10 | 35.13 | 36.53 | 32.50 | 35.40 | 38.03 | 33.40 | 36.37 | 38.50 | 33.73 | 36.17 | 38.20 | 34.37 | 37.07 | 39.73 |
| 22 | 30.97 | 33.07 | 35.53 | 28.73 | 34.07 | 37.13 | 32.47 | 35.67 | 37.90 | 32.40 | 35.23 | 37.47 | 33.87 | 36.80 | 39.40 |
| 23 | 31.93 | 33.77 | 35.17 | 31.13 | 33.80 | 36.70 | 32.20 | 35.07 | 37.40 | 32.27 | 34.77 | 36.93 | 33.43 | 36.43 | 38.97 |
| 24 | 32.23 | 33.70 | 35.00 | 32.03 | 33.83 | 36.47 | 32.13 | 34.90 | 37.03 | 32.43 | 34.50 | 36.53 | 32.97 | 36.03 | 38.47 |
| 26 | 32.77 | 34.20 | 35.30 | 32.33 | 34.60 | 36.80 | 32.43 | 34.87 | 36.73 | 32.80 | 34.73 | 36.60 | 32.97 | 35.77 | 38.27 |
| 27 | 32.27 | 34.03 | 35.03 | 31.43 | 34.10 | 36.50 | 32.23 | 34.73 | 36.60 | 32.63 | 34.53 | 36.33 | 33.03 | 35.40 | 38.00 |
| 29 | 32.27 | 33.73 | 34.73 | 31.97 | 33.97 | 36.37 | 32.07 | 34.23 | 36.10 | 32.37 | 34.13 | 35.83 | 32.10 | 34.80 | 37.27 |
| 30 | 32.17 | 33.77 | 34.57 | 31.93 | 33.90 | 36.27 | 31.93 | 34.03 | 36.00 | 32.33 | 34.03 | 35.77 | 32.40 | 34.43 | 36.97 |
| 31 | 32.33 | 33.77 | 34.77 | 32.20 | 34.10 | 36.13 | 32.00 | 34.10 | 36.03 | 32.57 | 34.27 | 35.90 | 31.33 | 34.70 | 37.00 |
| Average | 36.22 | 37.91 | 39.05 | 35.73 | 38.13 | 40.41 | 36.25 | 38.81 | 40.61 | 36.59 | 38.62 | 40.40 | 37.09 | 39.74 | 42.03 |

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TABLE 14.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. JANUARY, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 32.37 | 33.93 | 34.73 | 32.20 | 34.10 | 36.03 | 32.03 | 34.07 | 36.03 | 32.53 | 34.20 | 35.70 | 32.07 | 34.60 | 36.97 |
| 2 | 32.47 | 33.93 | 34.87 | 32.13 | 34.17 | 35.97 | 32.10 | 34.20 | 35.90 | 32.67 | 34.23 | 35.73 | 32.50 | 34.63 | 37.07 |
| 3 | 32.60 | 34.07 | 34.93 | 32.43 | 34.27 | 36.07 | 32.20 | 34.23 | 35.93 | 32.70 | 34.40 | 35.83 | 32.50 | 34.60 | 37.00 |
| 5 | 33.00 | 34.37 | 35.07 | 32.77 | 34.53 | 36.27 | 32.33 | 34.37 | 35.97 | 33.10 | 34.50 | 35.93 | 32.83 | 34.70 | 37.03 |
| 6 | 33.27 | 34.43 | 35.10 | 33.00 | 34.57 | 36.23 | 32.33 | 34.37 | 35.93 | 33.13 | 34.57 | 35.97 | 32.70 | 34.67 | 37.00 |
| 7 | 33.20 | 34.40 | 35.20 | 33.07 | 34.60 | 36.23 | 32.37 | 34.37 | 35.90 | 33.20 | 34.60 | 36.00 | 32.67 | 34.63 | 36.87 |
| 8 | 33.30 | 34.47 | 35.13 | 33.03 | 34.67 | 36.27 | 32.33 | 34.33 | 35.93 | 33.33 | 34.60 | 35.90 | 32.77 | 34.57 | 36.83 |
| 9 | 33.33 | 34.50 | 35.13 | 33.03 | 34.63 | 36.23 | 32.43 | 34.33 | 35.90 | 33.40 | 34.67 | 36.03 | 32.67 | 34.57 | 36.83 |
| 10 | 33.43 | 34.53 | 35.23 | 33.20 | 34.63 | 36.23 | 32.57 | 34.47 | 36.00 | 35.53 | 34.90 | 36.13 | 32.80 | 34.63 | 36.87 |
| 12 | 33.43 | 34.70 | 35.43 | 33.17 | 34.63 | 36.30 | 32.87 | 34.70 | 36.17 | 33.90 | 35.17 | 36.37 | 33.07 | 34.80 | 37.00 |
| 13 | 33.57 | 34.73 | 35.50 | 33.10 | 34.70 | 36.37 | 33.07 | 34.93 | 36.30 | 33.90 | 35.23 | 36.43 | 33.17 | 34.87 | 37.10 |
| 14 | 33.67 | 34.90 | 35.57 | 33.17 | 34.80 | 36.53 | 33.27 | 35.03 | 36.53 | 34.03 | 35.40 | 36.60 | 33.40 | 35.10 | 37.30 |
| 15 | 33.57 | 34.70 | 35.43 | 33.10 | 34.67 | 36.33 | 33.07 | 34.90 | 36.40 | 33.93 | 35.23 | 36.40 | 33.33 | 35.00 | 37.10 |
| 16 | 33.67 | 34.83 | 35.57 | 33.20 | 34.73 | 36.33 | 33.13 | 34.93 | 36.37 | 33.97 | 35.13 | 36.43 | 33.33 | 34.97 | 37.03 |
| 17 | 33.70 | 34.93 | 35.60 | 33.37 | 34.77 | 36.40 | 33.20 | 34.93 | 36.37 | 34.07 | 35.23 | 36.47 | 33.37 | 35.00 | 37.13 |
| 19 | 33.80 | 34.90 | 35.53 | 33.40 | 34.90 | 36.40 | 33.23 | 34.97 | 36.37 | 34.10 | 35.37 | 36.43 | 33.37 | 34.93 | 37.07 |
| 20 | 33.77 | 34.90 | 35.53 | 33.37 | 34.87 | 36.40 | 33.23 | 34.97 | 36.33 | 34.07 | 35.37 | 36.47 | 33.33 | 34.97 | 37.00 |
| 21 | 33.87 | 34.93 | 35.60 | 33.53 | 34.90 | 36.43 | 33.23 | 35.07 | 36.37 | 34.17 | 35.40 | 36.47 | 33.40 | 35.00 | 37.10 |
| 22 | 33.93 | 34.93 | 35.60 | 33.57 | 34.97 | 36.40 | 33.37 | 35.00 | 36.33 | 34.20 | 35.43 | 36.50 | 33.43 | 35.00 | 37.10 |
| 23 | 33.90 | 34.87 | 35.53 | 33.53 | 34.93 | 36.37 | 33.33 | 34.90 | 36.23 | 34.13 | 35.33 | 36.40 | 33.37 | 34.87 | 36.93 |
| 24 | 33.93 | 34.83 | 35.50 | 33.50 | 34.83 | 36.27 | 33.43 | 35.00 | 36.33 | 34.13 | 35.23 | 36.43 | 33.43 | 34.97 | 37.03 |
| 26 | 33.67 | 34.90 | 35.63 | 33.20 | 34.80 | 36.37 | 33.37 | 35.03 | 36.37 | 34.00 | 35.27 | 36.37 | 33.40 | 34.80 | 36.80 |
| 27 | 33.50 | 34.63 | 35.37 | 33.17 | 34.63 | 36.27 | 33.30 | 34.93 | 36.23 | 33.87 | 35.07 | 36.10 | 33.30 | 34.67 | 36.60 |
| 28 | 33.67 | 34.67 | 35.37 | 33.30 | 34.67 | 36.20 | 33.33 | 34.80 | 35.97 | 33.93 | 35.00 | 36.07 | 33.30 | 34.67 | 36.60 |
| 29 | 39.60 | 37.63 | 36.70 | 40.20 | 37.63 | 36.77 | 35.30 | 34.90 | 35.70 | 38.93 | 36.30 | 36.23 | 33.33 | 34.40 | 36.23 |
| 30 | 34.40 | 36.23 | 37.07 | 33.90 | 36.27 | 37.67 | 34.40 | 36.40 | 36.87 | 35.23 | 37.13 | 37.63 | 33.37 | 34.50 | 36.23 |
| 31 | 33.40 | 34.97 | 35.93 | 32.97 | 35.00 | 36.83 | 33.43 | 35.60 | 36.83 | 33.87 | 35.73 | 37.00 | 33.37 | 34.53 | 36.40 |
| Average | 33.70 | 34.81 | 35.48 | 33.39 | 34.85 | 36.38 | 33.05 | 34.80 | 36.21 | 34.00 | 35.14 | 36.30 | 33.10 | 34.76 | 36.90 |

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TABLE 15.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. FEBRUARY, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 2 | 33.53 | 34.80 | 35.57 | 33.20 | 34.90 | 36.47 | 33.30 | 35.13 | 36.47 | 33.90 | 35.20 | 36.40 | 33.47 | 34.90 | 36.80 |
| 3 | 33.40 | 34.57 | 35.30 | 33.07 | 34.57 | 36.13 | 33.03 | 34.80 | 36.13 | 33.60 | 34.97 | 36.13 | 33.33 | 34.73 | 36.63 |
| 4 | 33.60 | 34.73 | 35.43 | 33.37 | 34.77 | 36.27 | 33.37 | 34.93 | 36.20 | 33.87 | 35.07 | 36.27 | 33.40 | 34.80 | 36.70 |
| 5 | 33.70 | 34.77 | 35.47 | 33.37 | 34.83 | 36.37 | 33.37 | 35.03 | 36.20 | 33.93 | 35.13 | 36.20 | 33.50 | 34.87 | 36.77 |
| 6 | 33.70 | 34.80 | 35.47 | 33.23 | 34.70 | 36.27 | 33.30 | 34.93 | 36.17 | 33.90 | 35.07 | 36.17 | 33.40 | 34.83 | 36.73 |
| 7 | 33.70 | 34.80 | 35.43 | 33.23 | 34.70 | 36.13 | 33.33 | 34.93 | 36.07 | 33.93 | 35.00 | 36.13 | 33.43 | 34.83 | 36.57 |
| 9 | 33.90 | 35.00 | 35.63 | 33.27 | 34.83 | 36.33 | 33.43 | 35.07 | 36.23 | 34.07 | 35.23 | 36.23 | 33.67 | 35.00 | 36.87 |
| 10 | 33.73 | 34.83 | 35.50 | 33.07 | 34.57 | 36.17 | 33.33 | 34.93 | 36.03 | 33.90 | 35.07 | 36.17 | 33.57 | 34.87 | 36.73 |
| 11 | 33.63 | 34.77 | 35.43 | 32.97 | 34.60 | 36.20 | 33.27 | 34.93 | 36.17 | 33.90 | 35.10 | 36.17 | 33.60 | 34.87 | 36.73 |
| 12 | 33.70 | 34.93 | 35.50 | 32.93 | 34.63 | 36.17 | 33.43 | 35.10 | 36.17 | 34.07 | 35.17 | 36.27 | 33.70 | 35.07 | 36.87 |
| 13 | 33.53 | 34.70 | 35.37 | 32.33 | 34.43 | 36.13 | 33.30 | 35.00 | 36.20 | 33.83 | 35.07 | 36.17 | 33.70 | 35.00 | 36.77 |
| 14 | 33.20 | 34.37 | 35.13 | 32.13 | 34.17 | 35.77 | 33.07 | 34.73 | 35.93 | 33.60 | 34.77 | 35.87 | 33.50 | 34.77 | 36.63 |
| 16 | 33.13 | 34.27 | 34.97 | 32.33 | 34.10 | 35.67 | 32.90 | 34.60 | 35.77 | 33.50 | 34.70 | 35.73 | 33.40 | 34.73 | 36.53 |
| 17 | 33.30 | 34.37 | 34.97 | 32.37 | 34.03 | 35.60 | 32.90 | 34.60 | 35.73 | 33.50 | 34.77 | 35.70 | 33.43 | 34.67 | 36.50 |
| 18 | 33.27 | 34.27 | 34.90 | 32.40 | 34.03 | 35.57 | 32.90 | 34.50 | 35.67 | 33.50 | 34.67 | 35.70 | 33.33 | 34.60 | 36.47 |
| 19 | 33.27 | 34.27 | 34.90 | 32.47 | 34.07 | 35.53 | 32.90 | 34.43 | 35.57 | 33.57 | 34.63 | 35.63 | 33.33 | 34.53 | 36.37 |
| 20 | 33.40 | 34.33 | 35.07 | 32.63 | 34.23 | 35.70 | 33.07 | 34.57 | 35.67 | 33.67 | 34.80 | 35.70 | 33.40 | 34.67 | 36.43 |
| 21 | 33.43 | 34.43 | 35.03 | 32.70 | 34.23 | 35.73 | 33.10 | 34.60 | 35.70 | 33.70 | 34.77 | 35.77 | 33.40 | 34.67 | 36.47 |
| 23 | 33.47 | 34.50 | 35.00 | 32.77 | 34.33 | 35.73 | 33.17 | 34.63 | 35.67 | 33.80 | 34.90 | 35.77 | 33.43 | 34.70 | 36.50 |
| 24 | 33.23 | 34.27 | 34.87 | 32.50 | 33.80 | 35.57 | 32.87 | 34.53 | 35.53 | 33.57 | 34.70 | 35.60 | 33.27 | 34.57 | 36.30 |
| 25 | 33.40 | 34.60 | 35.20 | 32.80 | 34.40 | 35.90 | 33.20 | 34.70 | 35.90 | 33.90 | 35.00 | 35.90 | 33.50 | 34.90 | 36.60 |
| 26 | 33.13 | 34.17 | 34.87 | 32.20 | 34.00 | 35.47 | 32.83 | 34.43 | 35.50 | 33.47 | 34.57 | 35.50 | 33.23 | 34.50 | 36.33 |
| 27 | 33.13 | 34.13 | 34.67 | 32.50 | 33.93 | 35.33 | 32.70 | 34.27 | 35.27 | 33.47 | 34.53 | 35.43 | 33.13 | 34.37 | 36.17 |
| 28 | 33.07 | 33.93 | 34.60 | 32.50 | 33.87 | 35.33 | 32.70 | 34.20 | 35.30 | 33.43 | 34.43 | 35.30 | 32.93 | 34.33 | 36.03 |
| Average | 33.44 | 34.53 | 35.18 | 32.76 | 34.36 | 35.90 | 33.12 | 34.73 | 35.89 | 33.73 | 34.89 | 35.91 | 33.42 | 34.74 | 36.56 |

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TABLE 16.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. MARCH, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 2 | 33.50 | 34.30 | 34.80 | 32.97 | 34.17 | 35.40 | 33.17 | 34.53 | 35.53 | 33.83 | 34.80 | 35.70 | 33.30 | 34.57 | 36.33 |
| 3 | 33.27 | 34.20 | 34.77 | 32.77 | 34.13 | 35.47 | 33.13 | 34.50 | 35.43 | 33.70 | 34.73 | 35.57 | 33.20 | 34.43 | 36.13 |
| 4 | 33.30 | 34.23 | 34.67 | 32.73 | 34.10 | 35.33 | 33.07 | 34.43 | 35.40 | 33.73 | 34.67 | 35.50 | 33.33 | 34.40 | 36 10 |
| 5 | 33.30 | 34 23 | 34.70 | 32.80 | 34.17 | 35.40 | 32.97 | 34.37 | 35.33 | 33.70 | 34.67 | 35.43 | 33.17 | 34.37 | 36.00 |
| 6 | 33.37 | 34.20 | 34.67 | 32.77 | 33.87 | 34.90 | 32.97 | 34.40 | 35.33 | 33.73 | 34.63 | 35.37 | 33.13 | 34.30 | 36.03 |
| 7 | 33 40 | 34 23 | 34.73 | 32.93 | 33.93 | 35.00 | 33.10 | 34.43 | 35.37 | 33.67 | 34.67 | 35.50 | 33.17 | 34.33 | 36.00 |
| 9 | 33.37 | 34.27 | 34.80 | 33.07 | 34.20 | 35.37 | 33.03 | 34.43 | 35.30 | 33.77 | 34.67 | 35.47 | 33.17 | 34.27 | 35.90 |
| 10 | 33.47 | 34.33 | 34 83 | 33.17 | 34.17 | 35.27 | 33.07 | 34.40 | 35.33 | 33.73 | 34.70 | 35.43 | 33.17 | 34.23 | 35.97 |
| 11 | 33 40 | 34 23 | 34.77 | 33.17 | 34.10 | 35.27 | 33.07 | 34.37 | 35.23 | 33.80 | 34.63 | 35.37 | 33.13 | 34.23 | 35.97 |
| 12 | 33.47 | 34.37 | 34.80 | 33.20 | 34.23 | 35.33 | 33.10 | 34.43 | 35.33 | 33.73 | 34.70 | 35.47 | 33.17 | 34.30 | 35.93 |
| 13 | 33.43 | 34.13 | 34.53 | 33.03 | 34.07 | 35.20 | 32.97 | 34.27 | 35.10 | 33.60 | 34.50 | 35.20 | 33.17 | 34.17 | 35.70 |
| 14 | 35 27 | 34.90 | 34.80 | 34.17 | 34.33 | 35.10 | 32.87 | 34.10 | 34.77 | 33.47 | 34.07 | 35.00 | 33.00 | 33.83 | 35.33 |
| 16 | 40.83 | 39.00 | 38.07 | 41.63 | 38.93 | 37.53 | 38.07 | 36.23 | 35.70 | 39.63 | 36 97 | 36.80 | 33.07 | 33.83 | 35.10 |
| 17 | 36.03 | 37.07 | 37.47 | 35.70 | 37.03 | 37.83 | 35.80 | 37.27 | 37.00 | 36.77 | 36.90 | 37.83 | 33.07 | 34.00 | 35.53 |
| 18 | 34.60 | 35.97 | 36.63 | 34.27 | 36.03 | 37.17 | 34.60 | 36.37 | 37.00 | 35.23 | 35.80 | 37.27 | 33.23 | 34.40 | 36 03 |
| 19 | 34.17 | 35.27 | 36.00 | 33.37 | 35.10 | 36.77 | 34.07 | 35.77 | 36.63 | 34.67 | 36.00 | 36.83 | 33.33 | 34.53 | 36.33 |
| 20 | 34.00 | 34.93 | 35.60 | 32.60 | 34.53 | 36.10 | 33.80 | 35.40 | 36.30 | 34.27 | 35.50 | 36.37 | 33.27 | 34.60 | 36.47 |
| 21 | 33.70 | 34.77 | 35.37 | 32.23 | 34.23 | 35.77 | 33.57 | 35.07 | 36.07 | 33.97 | 34.60 | 36.10 | 33.33 | 34.63 | 36 43 |
| 23 | 33.50 | 34.43 | 35.06 | 32.70 | 34.17 | 35.50 | 33.33 | 34.70 | 35.57 | 33.73 | 34.07 | 35 63 | 33.13 | 34.43 | 36.20 |
| 24 | 35.53 | 35.07 | 35.13 | 35.27 | 34.97 | 35.53 | 34.50 | 34.63 | 35.47 | 34.97 | 34.37 | 35.50 | 33.20 | 34.43 | 36.10 |
| 25 | 39.00 | 36.80 | 36.07 | 38.90 | 36.33 | 35.80 | 36.87 | 35.23 | 35.13 | 37.50 | 35.10 | 35.40 | 32.47 | 33.47 | 35.07 |
| 26 | 42.17 | 39.43 | 38.27 | 42.17 | 38.97 | 37.50 | 39.87 | 37.33 | 36.27 | 40 60 | 37.57 | 36.87 | 32.53 | 33.50 | 35.10 |
| 27 | 41.33 | 41.90 | 41.30 | 40.90 | 41.50 | 40.23 | 41.73 | 40.93 | 38.37 | 42.43 | 41.17 | 39.47 | 32.67 | 33.83 | 35.37 |
| 28 | 41.63 | 39.87 | 39.37 | 41.70 | 39.63 | 39.10 | 40.37 | 39.23 | 38.60 | 40.93 | 39.30 | 39.17 | 32.87 | 34.03 | 35.73 |
| 30 | 42.80 | 43.00 | 42.43 | 42.43 | 42 60 | 41.67 | 43.20 | 42.43 | 40.43 | 43.63 | 42.57 | 41.33 | 39.03 | 36.73 | 37.40 |
| 31 | 43.77 | 41.67 | 41.10 | 44.40 | 41.63 | 40.87 | 42.20 | 41.07 | 40.40 | 42.53 | 41.07 | 40.87 | 39.90 | 38.20 | 38.53 |
| Average | 35.99 | 36.18 | 36.33 | 35.58 | 35.97 | 36.55 | 35.33 | 35.94 | 36.25 | 35.97 | 36.02 | 36.58 | 33.56 | 34.46 | 36.03 |

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TABLE 17.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. APRIL, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 44.37 | 43.27 | 42.50 | 44.37 | 43.10 | 42.00 | 43.70 | 42.47 | 40.87 | 44.13 | 42.37 | 41.50 | 42.50 | 39.73 | 39.60 |
| 2 | 40.27 | 41.40 | 41.70 | 39.87 | 41.20 | 41.70 | 40.83 | 41.93 | 41.10 | 41.10 | 41.83 | 41.70 | 41.43 | 40.83 | 40.37 |
| 3 | 39.90 | 39.80 | 40.07 | 40.03 | 39.77 | 40.47 | 39.40 | 40.27 | 40.53 | 39.83 | 40.13 | 40.70 | 39.87 | 40.57 | 40.83 |
| 4 | 36.20 | 38.00 | 39.03 | 36.33 | 38.17 | 39.83 | 36.30 | 39.20 | 40.00 | 36.53 | 38.90 | 40.13 | 36.73 | 40.27 | 40.90 |
| 6 | 34.67 | 36.67 | 37.67 | 34.27 | 36.87 | 38.53 | 34.93 | 37.53 | 38.47 | 35.03 | 37.30 | 38.37 | 36.80 | 38.63 | 39.90 |
| 7 | 35.27 | 36.03 | 36.67 | 35.10 | 36.20 | 37.67 | 34.40 | 36.37 | 37.63 | 35.23 | 36.27 | 37.57 | 35.57 | 37.80 | 39.33 |
| 8 | 34.07 | 35.90 | 36.73 | 33.73 | 35.90 | 37.47 | 33.73 | 36.10 | 37.30 | 34.37 | 36.27 | 37.40 | 34.93 | 37.10 | 38.80 |
| 9 | 33.83 | 35.07 | 35.97 | 33.80 | 35.33 | 36.93 | 33.17 | 35.47 | 36.87 | 33.53 | 35.47 | 36.90 | 34.43 | 36.50 | 38.33 |
| 10 | 35.67 | 35.47 | 35.93 | 36.57 | 35.87 | 36.70 | 33.90 | 35.10 | 36.37 | 34.30 | 34.97 | 36.30 | 34.00 | 35.93 | 37.87 |
| 11 | 39.40 | 38.17 | 37.80 | 40.67 | 38.73 | 37.90 | 37.27 | 36.47 | 36.57 | 38.00 | 36.80 | 36.70 | 34.43 | 35.63 | 37.33 |
| 13 | 42.80 | 40.17 | 39.43 | 43.90 | 40.67 | 39.63 | 40.47 | 38.73 | 38.00 | 40.50 | 38.97 | 38.57 | 37.53 | 36.63 | 37.43 |
| 14 | 47.43 | 43.30 | 41.83 | 48.20 | 43.40 | 41.20 | 45.07 | 41.00 | 39.23 | 44.60 | 41.17 | 39.83 | 40.30 | 37.50 | 37.87 |
| 15 | 50.27 | 46.70 | 44.97 | 50.47 | 46.37 | 43.68 | 48.63 | 44.53 | 41.17 | 47.97 | 44.47 | 42.10 | 43.83 | 39.37 | 38.73 |
| 16 | 50.60 | 47.47 | 45.93 | 50.67 | 47.07 | 44.67 | 49.40 | 45.77 | 42.83 | 48.77 | 45.70 | 43.70 | 45.60 | 41.20 | 40.10 |
| 17 | 54.13 | 49.43 | 47.37 | 54.53 | 48.97 | 45.83 | 52.03 | 47.27 | 43.97 | 51.23 | 46.80 | 44.80 | 47.77 | 42.87 | 41.40 |
| 18 | 59.47 | 53.43 | 50.47 | 59.77 | 52.83 | 48.30 | 56.93 | 50.17 | 45.57 | 56.03 | 50.00 | 46.70 | 51.73 | 44.80 | 42.77 |
| 20 | 44.87 | 47.27 | 48.17 | 43.83 | 46.43 | 47.60 | 46.60 | 49.40 | 48.00 | 46.53 | 48.57 | 48.67 | 48.70 | 48.27 | 46.30 |
| 21 | 47.50 | 45.73 | 45.57 | 48.13 | 45.57 | 45.43 | 46.57 | 46.13 | 46.03 | 46.27 | 45.57 | 46.13 | 46.90 | 47.00 | 46.57 |
| 22 | 53.20 | 49.90 | 48.33 | 53.67 | 49.80 | 47.47 | 51.60 | 48.17 | 45.87 | 51.20 | 47.90 | 46.40 | 49.83 | 46.83 | 46.30 |
| 23 | 52.33 | 50.30 | 49.17 | 52.37 | 49.87 | 48.27 | 51.27 | 49.27 | 46.97 | 50.43 | 48.80 | 47.47 | 50.07 | 47.47 | 46.40 |
| 24 | 51.87 | 50.30 | 49.50 | 51.73 | 49.90 | 48.50 | 51.13 | 49.60 | 47.37 | 50.43 | 49.03 | 47.83 | 50.20 | 47.73 | 46.77 |
| 25 | 55.83 | 52.20 | 50.57 | 56.83 | 52.27 | 49.33 | 54.37 | 50.43 | 47.73 | 54.27 | 50.27 | 48.27 | 52.40 | 48.10 | 47.00 |
| 27 | 59.33 | 54.90 | 52.87 | 60.97 | 55.43 | 51.87 | 57.03 | 52.70 | 49.37 | 56.90 | 52.47 | 50.40 | 55.07 | 50.53 | 48.67 |
| 28 | 62.37 | 58.10 | 55.63 | 63.90 | 58.60 | 54.20 | 60.87 | 55.77 | 51.23 | 60.63 | 55.53 | 52.30 | 59.00 | 52.43 | 49.80 |
| 29 | 58.50 | 57.63 | 56.43 | 58.80 | 57.73 | 55.17 | 59.17 | 56.97 | 52.67 | 59.00 | 56.90 | 53.87 | 59.93 | 54.40 | 51.47 |
| 30 | 52.57 | 52.53 | 52.67 | 53.57 | 52.67 | 52.47 | 53.03 | 53.70 | 52.30 | 52.33 | 53.03 | 52.87 | 54.93 | 54.50 | 52.60 |
| Average | 46.80 | 45.35 | 44.73 | 47.16 | 45.34 | 44.34 | 45.84 | 44.64 | 43.23 | 45.74 | 44.44 | 43.74 | 44.79 | 43.18 | 42.82 |

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TABLE 18.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. MAY, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 51.10 | 50.73 | 50.93 | 51.17 | 50.73 | 51.17 | 51.00 | 51.73 | 51.03 | 50.53 | 50.80 | 51.17 | 52.13 | 53.10 | 52.37 |
| 2 | 53.60 | 50.67 | 50.47 | 54.07 | 50.83 | 50.23 | 52.43 | 50.83 | 49.97 | 52.53 | 50.93 | 50.23 | 52.43 | 51.80 | 51.53 |
| 4 | 58.70 | 55.50 | 54.00 | 59.17 | 55.47 | 52.97 | 57.67 | 54.23 | 51.17 | 58.00 | 53.83 | 52.37 | 57.23 | 53.07 | 51.33 |
| 5 | 58.60 | 56.57 | 55.23 | 59.57 | 56.30 | 54.03 | 58.33 | 55.67 | 52.30 | 58.60 | 54.97 | 53.57 | 58.27 | 54.07 | 52.10 |
| 6 | 57.10 | 55.60 | 54.67 | 57.47 | 55.33 | 53.77 | 57.07 | 55.23 | 52.70 | 57.37 | 54.37 | 53.80 | 57.33 | 54.63 | 52.83 |
| 7 | 53.57 | 53.43 | 53.43 | 53.57 | 53.30 | 53.07 | 53.70 | 54.10 | 52.57 | 54.30 | 53.30 | 53.50 | 55.30 | 54.63 | 53.30 |
| 8 | 52.70 | 52.50 | 52.43 | 52.47 | 52.23 | 52.17 | 52.87 | 53.00 | 51.80 | 53.30 | 52.17 | 52.70 | 54.13 | 53.93 | 53.20 |
| 9 | 55.33 | 52.47 | 51.73 | 56.30 | 52.43 | 51.40 | 53.83 | 52.03 | 51.00 | 54.50 | 51.70 | 51.73 | 53.93 | 53.20 | 52.77 |
| 11 | 53.20 | 55.50 | 55.80 | 55.37 | 55.10 | 55.17 | 53.40 | 56.40 | 53.63 | 54.73 | 56.43 | 55.03 | 57.43 | 55.30 | 53.17 |
| 12 | 46.63 | 48.63 | 50.10 | 45.80 | 48.13 | 50.57 | 47.00 | 50.57 | 51.87 | 46.83 | 49.70 | 51.70 | 48.37 | 53.03 | 54.03 |
| 13 | 48.93 | 48.37 | 48.70 | 49.17 | 48.23 | 49.07 | 48.17 | 48.77 | 49.57 | 48.37 | 48.33 | 49.40 | 47.97 | 50.50 | 52.23 |
| 14 | 50.50 | 49.37 | 49.30 | 51.27 | 49.57 | 49.43 | 49.40 | 49.10 | 48.93 | 49.90 | 49.00 | 49.30 | 49.30 | 49.87 | 50.90 |
| 15 | 52.03 | 50.37 | 49.97 | 53.30 | 50.53 | 50.07 | 50.87 | 49.70 | 49.13 | 51.63 | 49.93 | 49.73 | 50.60 | 49.87 | 50.30 |
| 16 | 55.57 | 52.23 | 51.27 | 57.00 | 52.43 | 51.07 | 53.67 | 51.00 | 49.60 | 54.67 | 51.53 | 50.60 | 52.37 | 50.43 | 50.17 |
| 18 | 60.90 | 56.77 | 55.07 | 58.27 | 56.63 | 53.90 | 59.33 | 54.93 | 51.87 | 59.70 | 55.47 | 53.23 | 57.20 | 52.67 | 51.20 |
| 19 | 63.70 | 59.30 | 57.27 | 64.47 | 59.03 | 55.70 | 62.33 | 57.40 | 53.40 | 62.57 | 57.73 | 54.93 | 60.23 | 54.43 | 52.30 |
| 20 | 65.93 | 61.50 | 59.33 | 66.20 | 61.23 | 57.60 | 64.70 | 59.73 | 55.10 | 64.73 | 59.87 | 56.83 | 63.30 | 56.63 | 53.63 |
| 21 | 67.13 | 62.87 | 60.93 | 66.97 | 62.33 | 58.93 | 66.03 | 61.50 | 56.80 | 65.93 | 61.43 | 58.40 | 65.17 | 58.77 | 55.43 |
| 22 | 67.47 | 64.10 | 62.20 | 67.83 | 63.63 | 60.37 | 66.80 | 62.87 | 58.10 | 67.07 | 62.93 | 59.80 | 66.73 | 60.70 | 57.07 |
| 23 | 64.20 | 61.67 | 60.77 | 64.33 | 61.20 | 59.43 | 63.77 | 61.77 | 58.53 | 64.00 | 61.60 | 60.00 | 64.53 | 61.63 | 58.50 |
| 25 | 66.77 | 61.37 | 59.47 | 68.10 | 61.53 | 58.33 | 64.97 | 59.97 | 57.40 | 65.07 | 60.03 | 58.33 | 63.97 | 60.50 | 58.93 |
| 26 | 72.10 | 66.43 | 63.73 | 73.27 | 65.97 | 62.03 | 70.63 | 63.97 | 58.77 | 70.77 | 64.33 | 60.73 | 69.40 | 62.07 | 59.20 |
| 27 | 71.07 | 67.90 | 65.97 | 71.07 | 67.73 | 64.37 | 70.77 | 67.07 | 61.90 | 70.87 | 66.97 | 63.37 | 70.93 | 64.43 | 60.43 |
| 28 | 68.57 | 66.67 | 65.10 | 69.53 | 66.30 | 63.73 | 68.60 | 66.13 | 62.27 | 68.67 | 66.10 | 63.60 | 69.43 | 65.43 | 62.13 |
| 29 | 71.07 | 68.53 | 64.73 | 71.57 | 66.83 | 63.60 | 70.33 | 65.53 | 62.00 | 70.60 | 65.77 | 63.40 | 69.77 | 65.43 | 62.77 |
| 30 | 70.10 | 67.27 | 65.83 | 70.33 | 66.93 | 64.37 | 70.03 | 66.90 | 62.93 | 70.27 | 66.67 | 64.43 | 70.70 | 66.60 | 63.43 |
| Average | 59.87 | 57.47 | 56.48 | 60.29 | 57.31 | 55.64 | 59.14 | 56.93 | 54.40 | 59.44 | 56.73 | 55.46 | 59.16 | 56.41 | 54.82 |

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TABLE 19.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. JUNE, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 72.13 | 68.10 | 66.27 | 72.63 | 67.63 | 64.93 | 71.37 | 67.03 | 63.23 | 71.43 | 67.17 | 64.80 | 70.93 | 66.73 | 64.13 |
| 2 | 70.20 | 67.07 | 65.97 | 69.97 | 66.57 | 64.70 | 72.67 | 66.87 | 63.73 | 69.03 | 66.63 | 65.07 | 69.80 | 67.03 | 64.50 |
| 3 | 68.53 | 66.93 | 66.07 | 68.17 | 66.43 | 64.87 | 68.50 | 66.93 | 63.73 | 68.10 | 66.43 | 65.00 | 69.60 | 67.07 | 64.63 |
| 4 | 65.83 | 65.60 | 65.20 | 65.20 | 65.17 | 64.23 | 66.70 | 66.37 | 63.70 | 66.57 | 65.93 | 64.77 | 68.33 | 66.73 | 64.77 |
| 5 | 62.83 | 62.23 | 62.33 | 63.10 | 62.03 | 62.03 | 63.13 | 63.43 | 62.50 | 63.13 | 62.97 | 63.20 | 64.97 | 65.60 | 64.67 |
| 6 | 64.93 | 62.00 | 61.57 | 65.93 | 62.40 | 61.50 | 63.73 | 62.23 | 61.23 | 64.20 | 62.20 | 61.93 | 64.47 | 64.30 | 63.80 |
| 8 | 78.60 | 71.97 | 69.03 | 79.30 | 72.23 | 67.00 | 76.70 | 68.80 | 63.47 | 76.60 | 69.23 | 65.37 | 75.27 | 66.50 | 63.50 |
| 9 | 80.73 | 74.93 | 72.10 | 80.87 | 74.37 | 69.60 | 79.33 | 72.17 | 65.97 | 78.93 | 72.20 | 68.13 | 78.90 | 69.70 | 65.13 |
| 10 | 81.90 | 76.50 | 73.93 | 81.47 | 75.00 | 70.97 | 80.93 | 74.23 | 67.97 | 80.47 | 73.77 | 70.07 | 81.03 | 72.27 | 67.20 |
| 11 | 77.60 | 74.77 | 73.47 | 76.63 | 72.77 | 70.90 | 77.33 | 74.30 | 69.33 | 76.80 | 73.00 | 71.00 | 79.03 | 74.00 | 69.03 |
| 12 | 75.83 | 73.00 | 72.00 | 74.80 | 71.70 | 69.93 | 75.50 | 72.97 | 68.93 | 75.10 | 71.53 | 70.33 | 77.70 | 73.80 | 69.93 |
| 13 | 75.50 | 72.70 | 71.50 | 74.27 | 70.93 | 69.57 | 75.17 | 72.50 | 69.03 | 74.67 | 71.00 | 69.93 | 77.23 | 73.63 | 70.10 |
| 15 | 74.10 | 71.50 | 70.50 | 72.93 | 70.77 | 68.97 | 73.80 | 71.37 | 68.13 | 73.47 | 70.13 | 69.27 | 75.80 | 72.70 | 69.93 |
| 16 | 70.43 | 68.70 | 68.53 | 68.90 | 67.83 | 67.50 | 70.00 | 69.50 | 67.50 | 69.63 | 68.00 | 68.50 | 72.77 | 71.83 | 69.67 |
| 17 | 72.23 | 69.07 | 68.37 | 70.50 | 68.13 | 67.10 | 71.13 | 68.90 | 66.67 | 70.70 | 67.47 | 67.53 | 72.73 | 70.80 | 68.97 |
| 18 | 73.77 | 70.50 | 69.37 | 72.00 | 69.50 | 67.77 | 72.60 | 69.63 | 66.70 | 72.10 | 68.37 | 67.73 | 73.93 | 70.80 | 68.57 |
| 19 | 68.40 | 69.37 | 69.37 | 67.40 | 68.63 | 68.30 | 69.37 | 70.10 | 67.27 | 68.90 | 68.87 | 68.43 | 72.67 | 71.17 | 68.67 |
| 20 | 65.40 | 64.27 | 64.73 | 64.43 | 63.57 | 64.43 | 64.83 | 65.73 | 65.57 | 64.80 | 64.40 | 66.00 | 67.17 | 69.07 | 68.23 |
| 22 | 68.87 | 66.10 | 65.30 | 68.70 | 65.83 | 64.90 | 68.10 | 65.70 | 64.10 | 68.27 | 64.97 | 64.90 | 67.90 | 66.90 | 66.43 |
| 23 | 76.30 | 70.50 | 68.37 | 76.77 | 69.57 | 67.20 | 73.80 | 68.30 | 64.77 | 74.10 | 68.33 | 66.10 | 72.43 | 67.17 | 66.13 |
| 24 | 76.90 | 72.47 | 70.47 | 78.23 | 72.93 | 69.43 | 75.73 | 70.53 | 66.33 | 75.97 | 71.07 | 68.03 | 74.77 | 69.43 | 66.83 |
| 25 | 78.27 | 74.23 | 72.17 | 79.27 | 74.43 | 70.63 | 77.83 | 72.47 | 67.83 | 77.80 | 72.60 | 69.67 | 76.67 | 71.07 | 68.00 |
| 26 | 70.87 | 73.50 | 72.70 | 71.27 | 73.03 | 71.27 | 74.83 | 73.43 | 69.27 | 74.57 | 73.33 | 70.83 | 75.93 | 72.77 | 69.27 |
| 27 | 65.87 | 69.13 | 69.23 | 67.60 | 68.47 | 68.43 | 70.00 | 70.47 | 68.80 | 69.93 | 70.00 | 69.70 | 71.10 | 72.07 | 70.10 |
| 29 | 61.50 | 63.37 | 64.20 | 61.40 | 63.27 | 64.50 | 63.57 | 65.37 | 65.50 | 63.60 | 64.73 | 65.87 | 65.77 | 68.70 | 68.80 |
| 30 | 66.60 | 64.97 | 64.23 | 68.80 | 65.47 | 64.37 | 67.17 | 64.70 | 63.97 | 67.40 | 64.50 | 64.53 | 67.50 | 67.03 | 67.13 |
| Average | 71.71 | 69.36 | 68.35 | 71.56 | 68.79 | 67.12 | 71.69 | 69.00 | 65.97 | 71.40 | 68.42 | 67.18 | 72.48 | 69.57 | 67.24 |

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TABLE 20.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, JULY, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 65.47 | 65.90 | 65.97 | 65.43 | 65.90 | 65.77 | 66.23 | 66.40 | 64.47 | 66.13 | 66.30 | 65.53 | 68.13 | 67.37 | 66.40 |
| 2 | 65.47 | 64.50 | 64.40 | 66.17 | 64.47 | 64.23 | 65.70 | 64.93 | 63.97 | 65.97 | 64.63 | 64.70 | 66.60 | 66.40 | 66.07 |
| 3 | 69.27 | 69.53 | 65.17 | 70.97 | 66.50 | 64.83 | 68.70 | 65.50 | 63.73 | 69.20 | 65.53 | 64.80 | 68.90 | 66.27 | 65.60 |
| 4 | 70.03 | 68.93 | 67.67 | 68.27 | 68.90 | 66.83 | 71.20 | 67.90 | 64.90 | 71.27 | 68.10 | 66.23 | 71.57 | 67.57 | 65.80 |
| 6 | 77.77 | 73.30 | 71.37 | 78.03 | 73.13 | 69.90 | 76.40 | 71.63 | 67.20 | 75.93 | 71.03 | 68.90 | 76.80 | 70.63 | 67 43 |
| 7 | 78.50 | 74.57 | 72.67 | 77.67 | 74.13 | 71.00 | 77.33 | 73.07 | 68.67 | 76.67 | 72.37 | 70.17 | 78.17 | 72.47 | 68.83 |
| 8 | 79.00 | 75.10 | 73.43 | 78.40 | 74.70 | 71.63 | 78.03 | 74.00 | 69.67 | 77.57 | 73.20 | 71.03 | 79.03 | 73.80 | 70.07 |
| 9 | 79.47 | 75.37 | 73.73 | 78.37 | 74.87 | 71.93 | 78.33 | 74.27 | 70.23 | 77.60 | 73.13 | 71.53 | 79.47 | 74.63 | 71.10 |
| 10 | 81.57 | 76.87 | 75.27 | 80.30 | 76.30 | 72.97 | 80.23 | 75.50 | 70.93 | 80.23 | 74.37 | 72.33 | 80.90 | 75.57 | 71.83 |
| 11 | 82.87 | 78.57 | 76.60 | 81.63 | 77.83 | 74.43 | 81.87 | 77.23 | 72.03 | 81.27 | 76.00 | 73.63 | 82.83 | 76.93 | 72.90 |
| 13 | 78.23 | 76.93 | 76.17 | 76.93 | 76.27 | 74.73 | 78.80 | 77.43 | 73.53 | 78.43 | 76.30 | 74.63 | 80.83 | 78.03 | 74.57 |
| 14 | 73.00 | 73.33 | 73.50 | 71.87 | 72.93 | 72.73 | 74.47 | 74.90 | 72.33 | 74.13 | 74.00 | 73.33 | 77.10 | 76.97 | 74 77 |
| 15 | 73.43 | 71.73 | 71.40 | 73.03 | 71.50 | 70.83 | 73.63 | 72.57 | 70.77 | 73.47 | 72.10 | 71.50 | 75.23 | 75.00 | 73.87 |
| 16 | 78.17 | 74.13 | 72.53 | 79.87 | 74.50 | 71.70 | 77.63 | 73.27 | 70.27 | 77.27 | 72.77 | 71.23 | 77.40 | 74.30 | 72 87 |
| 17 | 80.83 | 77.10 | 75.33 | 81.73 | 77.60 | 74.37 | 80.63 | 75.97 | 71.40 | 79.83 | 75.47 | 73.00 | 80.80 | 76.03 | 72.90 |
| 18 | 74.33 | 74.37 | 74.33 | 73.60 | 74.13 | 73.70 | 75.20 | 75.47 | 72.33 | 74.23 | 74.33 | 73.53 | 77.80 | 76.53 | 73 63 |
| 20 | 75.73 | 72.10 | 71.07 | 75.27 | 72.00 | 70.50 | 74.77 | 71.77 | 69.70 | 73.93 | 70.93 | 70.30 | 75.20 | 73.40 | 72 27 |
| 21 | 78.00 | 74.60 | 73.27 | 77.30 | 74.30 | 72.20 | 77.20 | 73.60 | 70.23 | 76.27 | 72.43 | 71.20 | 77.57 | 74.03 | 71.87 |
| 22 | 79.97 | 76.80 | 75.03 | 79.40 | 73.33 | 73.60 | 79.90 | 75.47 | 71.33 | 78.90 | 73.77 | 72.43 | 80.40 | 75.33 | 72 43 |
| 23 | 77.97 | 77.37 | 76.30 | 77.23 | 76.83 | 74.73 | 79.07 | 76.90 | 72.60 | 78.47 | 74.63 | 73.90 | 80.70 | 76.80 | 73.40 |
| 24 | 77.17 | 75.43 | 74.83 | 75.63 | 75.50 | 73.73 | 76.67 | 75.07 | 72.53 | 75.97 | 73.63 | 73.70 | 78.97 | 76.60 | 74.00 |
| 25 | 79.53 | 76.53 | 75.13 | 78.23 | 76.00 | 73.77 | 79.57 | 75.80 | 72.30 | 78.80 | 74.87 | 73.53 | 80.03 | 76.43 | 74.00 |
| 27 | 77.10 | 77.27 | 76.67 | 75.47 | 76.60 | 75.17 | 78.33 | 77.30 | 73.80 | 77.53 | 75.60 | 74.90 | 80.43 | 78.00 | 74.90 |
| 28 | 73.63 | 73.17 | 73.30 | 72.33 | 72.53 | 72.40 | 74.73 | 74.40 | 72.67 | 74.43 | 72.23 | 73.50 | 76.70 | 76.70 | 75.00 |
| 29 | 73.93 | 71.27 | 71.30 | 73.23 | 70.87 | 70.93 | 73.53 | 72.53 | 71.33 | 73.03 | 70.97 | 71.90 | 74.80 | 75.27 | 74.23 |
| 30 | 73.60 | 72.00 | 71.63 | 72.37 | 71.63 | 71.03 | 73.63 | 72.37 | 70.60 | 72.77 | 70.53 | 71.27 | 74.90 | 74.40 | 73.33 |
| 31 | 74.90 | 73.30 | 72.67 | 72.70 | 72.87 | 71.80 | 74.87 | 73.00 | 70.60 | 74.00 | 71.53 | 71.40 | 75.93 | 74.17 | 72.83 |
| Average | 75.92 | 74.08 | 72.62 | 75.24 | 73.30 | 71.53 | 75.80 | 73.27 | 70.15 | 75.31 | 72.27 | 71.26 | 76.93 | 74.08 | 71.74 |

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TABLE 21.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. AUGUST, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | 77.17 | 74.70 | 73.67 | 75.83 | 74.10 | 72.33 | 76.93 | 73.73 | 70.87 | 76.23 | 71.83 | 71.73 | 77.30 | 74.30 | 72.57 |
| 3 | 76.87 | 74.97 | 73.97 | 73.93 | 74.23 | 72.73 | 77.07 | 74.40 | 71.63 | 76.23 | 73.00 | 72.57 | 77.77 | 75.13 | 73.27 |
| 4 | 75.97 | 74.03 | 73.50 | 73.93 | 73.13 | 72.30 | 75.43 | 73.93 | 71.70 | 74.60 | 72.03 | 72.57 | 78.33 | 75.30 | 73.47 |
| 5 | 77.00 | 74.27 | 73.60 | 74.77 | 73.40 | 72.47 | 76.00 | 74.00 | 71.57 | 75.00 | 71.90 | 72.40 | 76.43 | 75.20 | 73.40 |
| 6 | 73.93 | 75.03 | 74.33 | 75.27 | 74.20 | 73.00 | 76.60 | 74.50 | 71.70 | 75.87 | 72.63 | 72.67 | 76.70 | 75.33 | 73.50 |
| 7 | 78.57 | 76.33 | 75.03 | 77.63 | 75.40 | 73.50 | 78.97 | 75.33 | 72.00 | 78.07 | 73.43 | 73.17 | 79.07 | 75.50 | 73.60 |
| 8 | 80.80 | 77.27 | 76.10 | 79.00 | 76.23 | 74.43 | 79.73 | 76.33 | 72.90 | 78.77 | 74.23 | 74.03 | 79.87 | 76.47 | 74.00 |
| 10 | 77.47 | 76.60 | 76.27 | 76.03 | 75.83 | 74.90 | 77.83 | 76.90 | 74.00 | 77.33 | 75.53 | 75.00 | 78.73 | 77.40 | 75.13 |
| 11 | 75.53 | 72.50 | 73.00 | 74.63 | 71.97 | 72.37 | 73.53 | 74.27 | 72.90 | 73.13 | 72.83 | 73.63 | 75.63 | 76.00 | 75.10 |
| 12 | 72.03 | 70.63 | 70.77 | 71.50 | 70.43 | 70.73 | 72.33 | 72.03 | 71.33 | 71.70 | 70.80 | 71.87 | 73.37 | 74.70 | 74.23 |
| 13 | 70.90 | 71.07 | 71.27 | 70.30 | 70.80 | 71.07 | 72.00 | 72.33 | 70.67 | 71.43 | 71.33 | 71.40 | 73.40 | 73.87 | 73.27 |
| 14 | 68.80 | 68.73 | 69.30 | 68.07 | 68.53 | 69.23 | 69.27 | 70.10 | 69.60 | 68.87 | 69.50 | 70.13 | 70.63 | 72.33 | 72.33 |
| 15 | 69.23 | 67.77 | 67.97 | 69.67 | 68.17 | 68.33 | 69.27 | 68.83 | 68.50 | 69.13 | 68.33 | 68.97 | 69.27 | 70.90 | 71.33 |
| 17 | 71.40 | 70.23 | 69.87 | 71.77 | 70.30 | 69.60 | 71.47 | 70.10 | 68.33 | 71.53 | 69.93 | 69.27 | 71.53 | 70.20 | 69.90 |
| 18 | 74.90 | 72.27 | 71.30 | 75.60 | 72.47 | 70.70 | 74.50 | 71.33 | 68.87 | 74.60 | 71.40 | 70.03 | 74.10 | 70.93 | 69.97 |
| 19 | 76.40 | 73.67 | 72.87 | 75.47 | 73.57 | 71.93 | 75.60 | 73.07 | 69.93 | 75.77 | 72.97 | 71.27 | 75.57 | 72.20 | 70.57 |
| 20 | 75.60 | 73.77 | 73.17 | 75.23 | 73.63 | 72.27 | 75.53 | 73.37 | 70.60 | 75.63 | 73.33 | 71.87 | 75.60 | 73.03 | 71.33 |
| 21 | 75.40 | 73.47 | 72.93 | 75.77 | 73.50 | 72.23 | 75.33 | 73.47 | 70.90 | 75.63 | 73.23 | 72.10 | 75.50 | 73.43 | 71.87 |
| 22 | 75.13 | 73.23 | 73.80 | 75.73 | 73.17 | 72.17 | 75.37 | 73.53 | 71.17 | 74.97 | 73.03 | 72.20 | 74.97 | 73.77 | 72.23 |
| 24 | 71.57 | 72.37 | 72.83 | 70.77 | 72.00 | 72.27 | 72.43 | 73.43 | 71.37 | 71.73 | 72.67 | 72.40 | 74.00 | 74.23 | 72.73 |
| 25 | 68.30 | 67.97 | 68.87 | 67.67 | 67.17 | 68.87 | 68.17 | 69.63 | 69.80 | 67.47 | 68.60 | 70.13 | 69.23 | 72.30 | 72.30 |
| 26 | 69.27 | 68.37 | 68.73 | 68.43 | 68.13 | 68.63 | 68.90 | 69.17 | 68.60 | 68.13 | 68.13 | 68.93 | 69.90 | 71.03 | 71.13 |
| 27 | 72.10 | 69.93 | 69.57 | 71.13 | 69.83 | 69.20 | 71.47 | 69.60 | 68.10 | 70.30 | 68.80 | 68.70 | 71.70 | 70.53 | 70.33 |
| 28 | 68.83 | 69.27 | 69.57 | 67.93 | 68.80 | 69.30 | 68.90 | 69.80 | 68.47 | 68.23 | 68.90 | 69.17 | 70.77 | 70.77 | 70.13 |
| 29 | 65.93 | 66.47 | 67.20 | 65.30 | 66.10 | 67.30 | 66.23 | 67.60 | 67.50 | 66.10 | 66.83 | 67.83 | 67.67 | 69.77 | 69.83 |
| 31 | 69.03 | 66.93 | 66.50 | 68.53 | 68.83 | 66.43 | 68.20 | 66.53 | 65.67 | 68.30 | 66.13 | 66.20 | 67.50 | 67.33 | 68.07 |
| Average | 73.39 | 71.99 | 71.77 | 72.69 | 71.69 | 71.09 | 73.35 | 72.20 | 70.37 | 72.88 | 71.20 | 71.16 | 74.02 | 73.15 | 72.14 |

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TABLE 22.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. SEPTEMBER, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 71.40 | 69.53 | 68.83 | 70.77 | 69.63 | 68.47 | 71.00 | 68.83 | 66.83 | 71.07 | 68.53 | 67.63 | 70.13 | 68.07 | 67.67 |
| 2 | 69.27 | 69.20 | 69.20 | 68.50 | 68.93 | 68.90 | 69.73 | 69.27 | 67.37 | 69.67 | 69.00 | 68.43 | 69.97 | 68.90 | 68.20 |
| 3 | 65.33 | 65.67 | 66.43 | 64.57 | 65.77 | 66.77 | 65.97 | 67.00 | 66.77 | 65.83 | 66.53 | 67.47 | 66.87 | 68.53 | 68.53 |
| 4 | 63.63 | 64.30 | 65.13 | 62.80 | 64.23 | 65.60 | 64.23 | 65.70 | 65.83 | 63.90 | 65.10 | 66.33 | 65.43 | 67.47 | 68.07 |
| 5 | 64.30 | 64.00 | 64.47 | 63.90 | 63.83 | 64.83 | 64.10 | 64.77 | 64.87 | 63.80 | 64.17 | 65.17 | 64.37 | 66.40 | 67.17 |
| 7 | 61.60 | 63.33 | 64.37 | 61.00 | 63.17 | 64.77 | 62.87 | 64.80 | 64.60 | 62.93 | 64.23 | 65.23 | 64.37 | 65.93 | 66.27 |
| 8 | 60.57 | 61.20 | 62.30 | 60.23 | 61.10 | 62.97 | 61.23 | 62.90 | 63.57 | 61.20 | 62.40 | 63.90 | 62.30 | 64.83 | 65.80 |
| 9 | 61.00 | 60.97 | 61.73 | 60.53 | 60.60 | 62.17 | 61.10 | 62.17 | 62.60 | 60.83 | 61.53 | 63.03 | 61.30 | 63.70 | 64.90 |
| 10 | 59.30 | 60.50 | 61.63 | 57.93 | 60.13 | 62.13 | 59.63 | 61.87 | 62.23 | 59.40 | 61.17 | 62.53 | 60.63 | 63.13 | 64.23 |
| 11 | 58.23 | 59.67 | 60.80 | 57.60 | 59.43 | 61.40 | 58.77 | 60.97 | 61.47 | 58.67 | 60.33 | 61.80 | 59.67 | 62.23 | 63.50 |
| 12 | 57.33 | 57.73 | 58.80 | 56.77 | 57.40 | 59.53 | 57.10 | 58.97 | 60.33 | 57.30 | 58.43 | 60.53 | 57.53 | 61.00 | 62.70 |
| 14 | 62.07 | 60.93 | 60.90 | 62.53 | 61.13 | 61.23 | 61.53 | 60.57 | 59.90 | 61.77 | 60.47 | 60.80 | 61.10 | 60.60 | 61.57 |
| 15 | 65.87 | 63.87 | 63.20 | 66.00 | 64.07 | 63.03 | 64.83 | 62.63 | 61.07 | 65.03 | 62.67 | 62.10 | 63.83 | 61.60 | 61.70 |
| 16 | 68.33 | 65.60 | 64.67 | 68.37 | 65.67 | 64.23 | 67.30 | 64.23 | 62.13 | 67.23 | 64.23 | 63.27 | 66.00 | 62.90 | 62.37 |
| 17 | 67.10 | 65.60 | 65.23 | 66.60 | 65.43 | 64.83 | 66.40 | 65.03 | 63.23 | 65.87 | 64.67 | 64.30 | 66.10 | 64.17 | 63.30 |
| 18 | 67.50 | 65.87 | 65.50 | 66.83 | 65.63 | 65.10 | 66.70 | 65.47 | 63.77 | 66.10 | 64.87 | 64.57 | 66.43 | 64.97 | 64.13 |
| 19 | 67.97 | 66.30 | 65.97 | 67.60 | 66.13 | 65.47 | 67.23 | 65.93 | 64.20 | 66.53 | 65.30 | 64.87 | 67.23 | 65.63 | 64.73 |
| 21 | 73.60 | 70.17 | 68.33 | 73.53 | 69.83 | 67.67 | 72.43 | 68.43 | 65.67 | 71.80 | 68.00 | 66.47 | 71.80 | 67.37 | 66.03 |
| 22 | 72.40 | 70.80 | 69.97 | 72.10 | 70.53 | 68.93 | 72.13 | 69.93 | 66.77 | 71.70 | 69.53 | 67.93 | 72.53 | 68.93 | 66.83 |
| 23 | 64.20 | 66.33 | 67.30 | 63.37 | 65.90 | 67.13 | 65.50 | 67.90 | 66.87 | 65.33 | 67.27 | 67.57 | 68.23 | 69.17 | 67.90 |
| 24 | 58.83 | 60.80 | 62.47 | 57.00 | 60.30 | 63.10 | 59.63 | 63.47 | 64.73 | 59.60 | 62.60 | 64.97 | 62.47 | 67.07 | 67.50 |
| 25 | 58.70 | 59.37 | 60.60 | 57.30 | 59.17 | 61.30 | 58.97 | 61.27 | 62.50 | 58.97 | 60.47 | 62.37 | 60.70 | 64.67 | 66.10 |
| 26 | 58.33 | 58.93 | 59.90 | 58.03 | 58.77 | 60.67 | 58.33 | 60.30 | 61.23 | 58.23 | 59.60 | 60.90 | 60.00 | 63.07 | 64.53 |
| 28 | 60.30 | 59.87 | 60.47 | 59.57 | 59.77 | 60.93 | 59.60 | 60.30 | 60.40 | 59.30 | 59.73 | 60.53 | 60.40 | 61.80 | 62.63 |
| 29 | 62.10 | 60.83 | 60.97 | 61.23 | 60.77 | 61.27 | 61.00 | 60.63 | 60.40 | 60.83 | 60.30 | 60.93 | 61.40 | 61.60 | 62.30 |
| 30 | 62.20 | 61.57 | 61.77 | 61.23 | 61.37 | 61.90 | 61.13 | 61.50 | 60.77 | 61.13 | 61.10 | 61.07 | 62.23 | 62.00 | 62.20 |
| **Average** | **63.91** | **63.58** | **63.89** | **63.30** | **63.42** | **64.01** | **63.79** | **64.05** | **63.47** | **63.62** | **63.55** | **64.04** | **64.35** | **64.84** | **65.03** |

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TABLE 23.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. OCTOBER, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | 60.87 | 60.46 | 61.00 | 60.10 | 60.10 | 61.27 | 59.57 | 60.67 | 60.77 | 59.57 | 60.10 | 61.20 | 60.87 | 61.87 | 62.30 |
| 2 | 60.27 | 60.03 | 60.60 | 59.73 | 59.57 | 60.83 | 58.93 | 60.10 | 60.33 | 58.90 | 59.47 | 60.80 | 60.33 | 61.60 | 62.17 |
| 3 | 59.80 | 59.73 | 60.30 | 59.30 | 59.40 | 60.53 | 58.77 | 59.83 | 59.93 | 58.77 | 59.20 | 60.40 | 59.97 | 61.33 | 61.97 |
| 5 | 64.93 | 62.77 | 62.13 | 64.60 | 62.57 | 61.83 | 63.53 | 61.50 | 59.90 | 63.70 | 60.87 | 60.90 | 63.43 | 61.30 | 61.47 |
| 6 | 66.57 | 64.37 | 63.60 | 66.20 | 64.03 | 63.10 | 65.97 | 63.03 | 61.27 | 65.40 | 62.90 | 62.20 | 65.17 | 62.37 | 61.87 |
| 7 | 66.27 | 64.47 | 64.03 | 65.97 | 64.10 | 63.53 | 65.13 | 63.67 | 62.00 | 65.20 | 63.43 | 62.93 | 65.37 | 63.23 | 62.57 |
| 8 | 65.77 | 65.10 | 64.87 | 64.93 | 64.80 | 64.20 | 65.50 | 64.53 | 62.63 | 65.43 | 64.43 | 63.70 | 66.20 | 64.10 | 63.13 |
| 9 | 66.97 | 64.90 | 64.43 | 65.83 | 64.67 | 63.97 | 65.97 | 64.47 | 62.83 | 66.17 | 64.27 | 63.60 | 66.03 | 64.30 | 63.63 |
| 10 | 65.10 | 64.97 | 64.97 | 64.60 | 64.73 | 64.47 | 65.33 | 65.00 | 63.23 | 65.33 | 64.93 | 64.30 | 66.23 | 64.90 | 64.07 |
| 12 | 55.93 | 58.03 | 59.63 | 54.20 | 57.37 | 66.20 | 56.77 | 60.30 | 61.37 | 56.83 | 59.83 | 61.60 | 59.23 | 63.00 | 63.87 |
| 13 | 53.43 | 56.23 | 57.90 | 51.57 | 55.93 | 58.63 | 54.60 | 58.70 | 59.57 | 54.77 | 57.93 | 59.97 | 55.17 | 61.40 | 62.87 |
| 14 | 51.17 | 53.33 | 55.03 | 49.80 | 53.13 | 56.33 | 51.73 | 55.33 | 57.60 | 51.93 | 55.07 | 57.87 | 54.50 | 59.30 | 61.50 |
| 15 | 55.53 | 54.87 | 55.33 | 54.83 | 54.97 | 56.17 | 54.83 | 55.13 | 56.20 | 55.13 | 55.00 | 56.47 | 55.13 | 57.57 | 59.90 |
| 16 | 57.27 | 57.63 | 57.20 | 56.23 | 57.20 | 57.60 | 57.13 | 56.67 | 56.37 | 57.33 | 56.80 | 57.03 | 57.03 | 57.37 | 58.80 |
| 17 | 56.13 | 56.57 | 57.17 | 55.40 | 56.43 | 57.53 | 55.97 | 56.83 | 56.87 | 56.27 | 56.73 | 57.43 | 56.47 | 57.27 | 58.20 |
| 19 | 54.83 | 55.33 | 56.13 | 54.70 | 55.13 | 56.80 | 54.57 | 55.97 | 56.57 | 54.73 | 55.73 | 56.97 | 54.67 | 56.73 | 58.10 |
| 20 | 56.10 | 55.67 | 56.17 | 56.03 | 55.87 | 56.70 | 55.57 | 55.93 | 56.20 | 55.83 | 55.37 | 56.47 | 55.37 | 56.63 | 57.73 |
| 21 | 57.33 | 56.80 | 57.07 | 57.27 | 57.13 | 57.60 | 56.93 | 56.77 | 56.37 | 57.23 | 56.77 | 57.13 | 56.53 | 56.63 | 57.53 |
| 22 | 57.53 | 57.10 | 57.43 | 57.13 | 57.33 | 57.77 | 57.03 | 57.23 | 56.83 | 57.30 | 57.23 | 57.63 | 56.77 | 57.00 | 57.70 |
| 23 | 55.97 | 56.30 | 57.13 | 55.73 | 56.40 | 57.50 | 55.77 | 56.90 | 56.83 | 56.03 | 56.87 | 57.57 | 56.17 | 57.10 | 57.77 |
| 24 | 53.00 | 54.93 | 56.50 | 52.40 | 55.37 | 57.20 | 53.77 | 56.17 | 56.77 | 54.10 | 56.33 | 57.43 | 55.30 | 57.03 | 57.80 |
| 26 | 48.23 | 49.47 | 51.27 | 48.23 | 48.77 | 52.80 | 48.27 | 51.37 | 53.47 | 49.00 | 51.10 | 53.50 | 49.83 | 53.87 | 56.47 |
| 27 | 41.27 | 43.00 | 48.07 | 44.67 | 46.77 | 49.20 | 41.80 | 48.47 | 51.67 | 52.57 | 48.03 | 50.87 | 46.40 | 52.17 | 55.20 |
| 28 | 43.10 | 45.40 | 47.20 | 42.17 | 45.03 | 48.37 | 42.37 | 46.83 | 49.60 | 42.97 | 45.63 | 49.10 | 43.97 | 49.90 | 53.57 |
| 29 | 45.13 | 46.90 | 48.23 | 43.70 | 47.47 | 48.03 | 45.60 | 47.30 | 48.77 | 46.13 | 47.43 | 48.70 | 45.70 | 48.80 | 52.10 |
| 30 | 44.23 | 45.87 | 47.40 | 44.13 | 45.53 | 48.10 | 43.67 | 46.03 | 49 03 | 44.10 | 46.27 | 48.60 | 44.37 | 48.13 | 51.10 |
| 31 | 45.57 | 46.13 | 47.40 | 45.60 | 46.33 | 48.03 | 45.37 | 46.43 | 48.13 | 45.67 | 46.40 | 48.30 | 44.70 | 47.60 | 50.33 |
| Average | 55.86 | 56.16 | 56.97 | 55.54 | 56.15 | 57.57 | 55.56 | 56.71 | 57.45 | 55.79 | 56.45 | 57.51 | 56.33 | 57.87 | 59.03 |



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TABLE 24.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND. NOVEMBER, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 | 48.27 | 49.30 | 50.00 | 47.53 | 49.47 | 50.83 | 48.07 | 49.33 | 49.73 | 48.40 | 49.20 | 50.43 | 47.93 | 48.77 | 50.30 |
| 3 | 49.70 | 49.30 | 49.73 | 48.80 | 49.60 | 50.37 | 48.83 | 49.20 | 49.77 | 49.30 | 49.23 | 50.07 | 48.17 | 49.00 | 50.63 |
| 4 | 47.60 | 49.10 | 49.97 | 46.67 | 49.40 | 50.83 | 48.17 | 49.70 | 50.13 | 48.47 | 49.60 | 50.70 | 48.40 | 49.57 | 50.83 |
| 5 | 44.20 | 46.60 | 48.13 | 41.50 | 46.50 | 49.40 | 45.10 | 48.33 | 49.63 | 45.30 | 48.07 | 50.03 | 46.50 | 49.43 | 51.10 |
| 6 | 42.77 | 44.90 | 46.30 | 42.03 | 45.10 | 47.67 | 43.80 | 46.47 | 47.30 | 43.87 | 46.27 | 48.67 | 44.60 | 48.37 | 50.80 |
| 7 | 46.33 | 45.97 | 46.50 | 45.33 | 46.10 | 47.50 | 45.80 | 46.17 | 47.67 | 46.17 | 46.23 | 47.90 | 44.90 | 47.53 | 50.00 |
| 9 | 39.17 | 41.67 | 43.73 | 37.00 | 42.20 | 45.40 | 40.03 | 44.03 | 46.77 | 39.87 | 44.00 | 46.70 | 42.10 | 46.70 | 49.17 |
| 10 | 41.00 | 42.23 | 43.43 | 39.10 | 42.23 | 44.87 | 40.43 | 43.10 | 45.33 | 41.17 | 43.00 | 45.47 | 40.93 | 45.27 | 48.30 |
| 11 | 40.27 | 41.93 | 43.23 | 39.90 | 42.20 | 44.73 | 40.37 | 42.83 | 44.90 | 41.23 | 42.93 | 45.20 | 40.83 | 44.73 | 47.43 |
| 12 | 39.33 | 41.17 | 42.63 | 36.33 | 41.17 | 44.17 | 39.60 | 42.47 | 44.63 | 40.00 | 42.33 | 40.77 | 40.30 | 43.97 | 46.83 |
| 13 | 42.13 | 42.90 | 43.50 | 38.30 | 43.27 | 44.73 | 41.80 | 42.87 | 44.20 | 42.40 | 42.97 | 44.53 | 41.30 | 43.50 | 46.30 |
| 14 | 39.57 | 41.30 | 42.67 | 38.03 | 41.33 | 44.03 | 39.90 | 42.27 | 44.27 | 40.30 | 42.23 | 44.43 | 40.17 | 43.37 | 45.93 |
| 16 | 38.07 | 41.60 | 43.53 | 37.43 | 41.57 | 44.83 | 39.17 | 43.23 | 44.70 | 39.50 | 43.10 | 45.20 | 40.50 | 43.80 | 45.77 |
| 17 | 35.83 | 38.93 | 40.80 | 35.13 | 39.00 | 42.50 | 36.53 | 40.97 | 43.77 | 36.70 | 40.67 | 43.37 | 38.90 | 43.13 | 45.70 |
| 18 | 33.63 | 37.00 | 38.93 | 33.23 | 47.17 | 40.87 | 34.60 | 39.27 | 42.37 | 34.67 | 38.60 | 41.87 | 37.07 | 41.93 | 45.20 |
| 19 | 33.80 | 36.47 | 38.10 | 33.43 | 36.73 | 39.93 | 34.37 | 38.10 | 41.13 | 34.57 | 37.73 | 40.73 | 36.20 | 40.83 | 44.33 |
| 20 | 33.83 | 36.33 | 37.80 | 33.23 | 36.40 | 39.53 | 34.07 | 37.63 | 40.47 | 34.50 | 37.30 | 40.13 | 35.67 | 39.97 | 43.40 |
| 21 | 33.70 | 36.17 | 37.53 | 33.10 | 36.13 | 39.20 | 33.93 | 37.27 | 39.80 | 34.40 | 37.03 | 39.63 | 35.17 | 39.40 | 42.57 |
| 23 | 32.57 | 35.33 | 36.93 | 31.83 | 35.40 | 38.53 | 33.60 | 36.80 | 39.27 | 34.00 | 36.63 | 39.10 | 34.60 | 38.27 | 41.47 |
| 24 | 32.13 | 34.70 | 36.37 | 31.63 | 34.80 | 37.93 | 33.37 | 36.43 | 38.67 | 33.60 | 36.27 | 38.60 | 34.33 | 37.83 | 40.93 |
| 25 | 32.57 | 34.83 | 36.23 | 32.27 | 34.90 | 37.80 | 33.33 | 36.17 | 38.27 | 33.87 | 36.13 | 38.27 | 34.23 | 37.53 | 40.63 |
| 26 | 37.67 | 36.70 | 36.97 | 37.13 | 36.67 | 38.10 | 35.67 | 36.30 | 38.07 | 37.23 | 36.70 | 38.23 | 34.10 | 37.30 | 40.30 |
| 27 | 38.10 | 39.70 | 40.17 | 37.67 | 39.87 | 40.83 | 38.40 | 39.07 | 39.33 | 39.33 | 39.87 | 40.23 | 34.67 | 37.30 | 40.13 |
| 28 | 34.87 | 37.47 | 38.73 | 34.30 | 37.43 | 39.93 | 35.30 | 38.43 | 40.07 | 35.72 | 38.53 | 40.57 | 35.13 | 37.50 | 40.33 |
| 30 | 44.50 | 42.53 | 41.63 | 44.67 | 42.90 | 41.93 | 43.03 | 40.37 | 39.93 | 43.77 | 40.83 | 40.50 | 39.30 | 37.97 | 40.37 |
| Average | 39.26 | 40.97 | 42.14 | 38.22 | 41.50 | 43.46 | 39.49 | 41.87 | 43.61 | 39.93 | 41.72 | 43.65 | 39.84 | 42.92 | 45.55 |

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BEGINNING WITH FOURTH YEAR.

TABLE 25.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, DECEMBER, 1914.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 2 | 46.00 | 42.97 | 46.50 | 45.47 | 49.43 | 46.57 | 45.90 | 46.17 | 45.30 | 46.27 | 46.17 | 46.17 | 45.73 | 45.40 | 45.40 |
| 3 | 38.73 | 39.80 | 40.87 | 37.57 | 38.63 | 40.27 | 38.57 | 40.57 | 41.13 | 39.23 | 40.67 | 41.73 | 40.17 | 41.67 | 43.37 |
| 4 | 35.57 | 36.57 | 37.68 | 35.57 | 36.40 | 37.43 | 39.03 | 37.23 | 37.83 | 36.13 | 37.20 | 38.33 | 37.03 | 38.57 | 40.70 |
| 5 | 36.57 | 37.03 | 37.43 | 36.63 | 37.00 | 37.57 | 36.20 | 37.00 | 37.17 | 37.03 | 37.00 | 37.60 | 36.80 | 37.63 | 39.30 |
| 7 | 33.77 | 34.53 | 35.37 | 33.47 | 34.30 | 35.33 | 33.67 | 34.97 | 35.47 | 34.13 | 34.93 | 35.87 | 34.90 | 36.07 | 37.70 |
| 8 | 32.47 | 33.57 | 34.33 | 32.47 | 33.47 | 34.37 | 32.53 | 33.87 | 34.27 | 32.97 | 33.70 | 34.60 | 33.60 | 34.77 | 36.73 |
| 9 | 32.37 | 33.30 | 34.07 | 32.07 | 33.33 | 34.17 | 32.40 | 33.63 | 34.03 | 32.67 | 33.40 | 34.27 | 33.40 | 34.30 | 36.07 |
| 10 | 32.00 | 33.10 | 33.87 | 31.80 | 32.90 | 33.77 | 32.40 | 33.50 | 33.80 | 32.30 | 33.07 | 33.83 | 33.10 | 33.90 | 35.53 |
| 11 | 30.63 | 32.40 | 33.27 | 28.50 | 31.10 | 32.77 | 32.10 | 33.20 | 33.53 | 31.17 | 32.23 | 33.30 | 32.27 | 33.57 | 35.20 |
| 12 | 30.17 | 31.60 | 32.53 | 28.57 | 30.27 | 31.97 | 31.53 | 32.83 | 33.13 | 30.07 | 31.53 | 32.47 | 32.30 | 33.30 | 34.77 |
| 14 | 30.17 | 31.87 | 32.70 | 25.23 | 28.33 | 31.13 | 31.37 | 32.73 | 33.13 | 30.70 | 31.90 | 32.70 | 32.27 | 33.00 | 34.43 |
| 15 | 28.73 | 30.17 | 31.30 | 23.23 | 26.03 | 28.30 | 30.20 | 32.13 | 32.57 | 28.33 | 30.03 | 31.67 | 31.33 | 32.67 | 34.13 |
| 16 | 28.60 | 30.07 | 31.00 | 22.10 | 25.33 | 27.60 | 29.90 | 31.77 | 32.43 | 28.17 | 29.70 | 31.13 | 31.23 | 32.43 | 33.97 |
| 17 | 28.37 | 29.87 | 30.73 | 22.80 | 25.23 | 27.10 | 29.60 | 31.43 | 32.57 | 28.13 | 29.50 | 30.83 | 31.00 | 32.33 | 33.70 |
| 18 | 28.93 | 29.87 | 30.50 | 24.93 | 26.17 | 27.37 | 29.63 | 31.10 | 31.83 | 28.63 | 29.33 | 30.47 | 30.97 | 32.10 | 33.47 |
| 19 | 31.10 | 31.57 | 31.77 | 29.87 | 30.93 | 31.27 | 30.83 | 31.57 | 31.79 | 30.60 | 30.83 | 31.23 | 31.87 | 32.00 | 33.37 |
| 21 | 31.17 | 31.70 | 31.97 | 29.37 | 30.70 | 31.23 | 30.93 | 31.77 | 31.70 | 31.00 | 31.20 | 31.63 | 31.70 | 32.00 | 32.27 |
| 22 | 31.17 | 31.80 | 32.07 | 29.00 | 30.00 | 30.83 | 30.70 | 31.70 | 31.90 | 31.00 | 31.27 | 31.90 | 31.63 | 32.10 | 33.27 |
| 23 | 31.23 | 31.83 | 32.17 | 29.17 | 30.23 | 31.07 | 30.67 | 31.60 | 31.90 | 30.93 | 31.37 | 31.83 | 31.53 | 32.03 | 33.17 |
| 24 | 31.33 | 31.97 | 32.23 | 28.90 | 30.53 | 31.27 | 30.47 | 31.63 | 31.80 | 31.37 | 31.37 | 31.90 | 31.56 | 32.03 | 33.20 |
| 26 | 30.50 | 31.30 | 31.90 | 26.77 | 28.60 | 29.90 | 30.33 | 31.37 | 31.63 | 30.27 | 30.97 | 31.67 | 30.87 | 31.83 | 33.10 |
| 28 | 31.43 | 31.97 | 32.10 | 29.40 | 30.93 | 31.43 | 30.73 | 31.50 | 31.53 | 31.10 | 31.30 | 31.67 | 31.50 | 31.63 | 32.67 |
| 29 | 31 80 | 32.20 | 32.27 | 30.67 | 31.70 | 32.00 | 31.07 | 31.67 | 31.63 | 31.47 | 31.50 | 31.87 | 31.90 | 31.73 | 32.60 |
| 30 | 32.10 | 32.37 | 32.33 | 31.53 | 32.13 | 32.33 | 31.33 | 31 97 | 31.80 | 31.80 | 31.83 | 32.07 | 32.03 | 31.87 | 32.70 |
| 31 | 31.93 | 32.40 | 32.43 | 30.63 | 31.60 | 32.17 | 31.27 | 32.10 | 31.93 | 31.60 | 31.93 | 32.20 | 31.77 | 31.97 | 32.80 |
| Average | 32.28 | 33.03 | 33.73 | 30.23 | 31.81 | 32.77 | 32.54 | 33.56 | 33.83 | 32.29 | 32.96 | 33.72 | 33.30 | 34.04 | 35.35 |

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TABLE 26.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JANUARY, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 2 | 32.13 | 32.40 | 32.43 | 31.43 | 32.10 | 32.33 | 31.37 | 32.03 | 31.90 | 31.93 | 31.93 | 32.20 | 31.90 | 31.80 | 32.70 |
| 4 | 31.73 | 32.30 | 32.40 | 30.87 | 31.53 | 32.13 | 30.97 | 31.73 | 31.73 | 31.40 | 31.57 | 32.10 | 31.30 | 31.53 | 32.50 |
| 5 | 32.00 | 32.30 | 32.33 | 31.43 | 32.00 | 32.27 | 31.13 | 31.73 | 31.60 | 31.67 | 31.33 | 32.10 | 31.57 | 31.53 | 32.37 |
| 6 | 32.13 | 32.30 | 32.37 | 31.83 | 32.13 | 32.30 | 31.33 | 31.93 | 31.63 | 32.07 | 31.67 | 32.17 | 32.00 | 31.63 | 32.37 |
| 7 | 32.27 | 32.47 | 32.43 | 32.10 | 32.33 | 32.40 | 31.80 | 32.10 | 31.83 | 32.43 | 32.30 | 32.30 | 32.33 | 31.93 | 32.37 |
| 8 | 32.33 | 32.53 | 32.63 | 32.13 | 32.37 | 32.43 | 31.93 | 32.20 | 31.97 | 32.50 | 32.37 | 32.30 | 32.30 | 32.03 | 32.47 |
| 9 | 32.33 | 32.60 | 32.87 | 31.83 | 32.37 | 32.57 | 31.87 | 32.27 | 32.03 | 32.53 | 32.40 | 32.33 | 32.43 | 32.03 | 32.57 |
| 11 | 32.20 | 32.57 | 32.80 | 31.87 | 32.27 | 32.60 | 31.50 | 32.17 | 32.00 | 32.17 | 32.27 | 32.30 | 32.30 | 31.93 | 32.43 |
| 12 | 32.30 | 32.77 | 33.03 | 31.93 | 32.40 | 32.67 | 31.73 | 32.23 | 32.03 | 32.37 | 32.30 | 32.43 | 32.30 | 31.97 | 32.57 |
| 13 | 32.30 | 32.80 | 33.07 | 31.97 | 32.33 | 32.77 | 31.73 | 32.20 | 32.07 | 32.30 | 32.30 | 32.47 | 32.30 | 32.03 | 32.53 |
| 14 | 32.30 | 32.73 | 33.07 | 31.73 | 32.33 | 32.83 | 31.47 | 32.20 | 32.07 | 32.20 | 32.30 | 32.53 | 32.30 | 31.87 | 32.53 |
| 15 | 32.30 | 32.80 | 33.17 | 31.50 | 32.37 | 32.83 | 31.57 | 32.17 | 32.07 | 32.27 | 32.27 | 32.60 | 32.30 | 31.97 | 32.53 |
| 16 | 32.33 | 32.87 | 33.17 | 31.00 | 32.37 | 32.93 | 31.47 | 32.17 | 32.07 | 32.20 | 32.30 | 32.60 | 32.30 | 31.97 | 32.57 |
| 18 | 32.37 | 32.87 | 33.13 | 32.13 | 32.53 | 32.83 | 31.93 | 32.30 | 32.13 | 32.47 | 32.40 | 32.67 | 32.30 | 32.03 | 32.47 |
| 19 | 32.40 | 32.87 | 33.17 | 32.10 | 32.53 | 33.00 | 31.90 | 32.23 | 32.13 | 32.30 | 32.40 | 32.77 | 32.80 | 31.97 | 32.47 |
| 20 | 32.30 | 32.85 | 33.15 | 32.10 | 32.50 | 32.95 | 31.75 | 32.35 | 32.25 | 32.20 | 32.40 | 32.85 | 32.35 | 32.00 | 32.50 |
| 21 | 32.30 | 32.77 | 33.17 | 31.53 | 32.27 | 32.87 | 31.57 | 32.30 | 32.27 | 32.17 | 32.30 | 32.90 | 32.37 | 32.07 | 32.63 |
| 22 | 32.17 | 32.83 | 33.20 | 30.33 | 31.37 | 32.67 | 31.40 | 32.37 | 32.37 | 31.87 | 32.37 | 32.93 | 32.43 | 32.17 | 32.80 |
| 23 | 32.07 | 32.57 | 33.00 | 30.27 | 30.90 | 32.30 | 31.33 | 32.27 | 32.30 | 32.03 | 32.27 | 32.67 | 32.33 | 32.10 | 32.73 |
| 25 | 31.27 | 31.97 | 32.47 | 29.17 | 29.93 | 31.07 | 30.97 | 32.07 | 32.17 | 31.47 | 31.97 | 32.50 | 32.00 | 32.07 | 32.70 |
| 26 | 30.97 | 31.83 | 32.37 | 28.53 | 29.83 | 30.80 | 30.73 | 31.97 | 32.13 | 31.30 | 31.77 | 32.43 | 31.87 | 32.07 | 32.73 |
| 27 | 30.70 | 31.40 | 32.13 | 27.70 | 28.63 | 30.07 | 30.57 | 31.87 | 32.10 | 31.13 | 31.63 | 32.40 | 31.70 | 31.97 | 32.77 |
| 28 | 30.47 | 31.13 | 32.03 | 27.43 | 28.50 | 29.97 | 30.43 | 31.70 | 31.97 | 30.93 | 31.57 | 32.43 | 31.63 | 32.00 | 32.90 |
| 29 | 30.37 | 30.97 | 31.67 | 27.23 | 28.27 | 29.60 | 30.33 | 31.47 | 31.90 | 30.73 | 31.33 | 32.30 | 31.47 | 31.87 | 32.77 |
| 30 | 29.07 | 29.90 | 30.87 | 24.63 | 25 83 | 27.77 | 29.53 | 31.03 | 31.67 | 30.17 | 30.83 | 32.17 | 30.80 | 31.57 | 32.47 |
| Average | 31.61 | 32.30 | 32.65 | 30.59 | 31.28 | 31.96 | 31.28 | 32.05 | 32.02 | 31.87 | 32.03 | 32.46 | 32.05 | 31.93 | 32.58 |

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TABLE 27.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, FEBRUARY, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 | 32.10 | 32.17 | 32.20 | 32.13 | 32.33 | 32.43 | 31.27 | 31.63 | 31.50 | 32.03 | 31.77 | 32.10 | 32.17 | 31.70 | 32.43 |
| 2 | 32.30 | 32.40 | 32.40 | 32.23 | 32.40 | 32.57 | 31.57 | 32.03 | 31.63 | 31.80 | 32.00 | 32.30 | 32.30 | 31.93 | 32.47 |
| 3 | 32.03 | 32.40 | 32.40 | 32.23 | 32.47 | 32.50 | 31.30 | 32.03 | 31.70 | 31.07 | 31.40 | 32.30 | 32.33 | 31.93 | 32.47 |
| 4 | 31.07 | 31.73 | 32.17 | 32.20 | 32.43 | 32.50 | 31.03 | 31.80 | 31.70 | 30.80 | 31.20 | 32.00 | 32.30 | 31.87 | 32.43 |
| 5 | 32.00 | 32.30 | 32.83 | 32.10 | 32.37 | 32.40 | 31.27 | 31.83 | 31.53 | 31.73 | 31.63 | 32.03 | 32.20 | 31.87 | 32.37 |
| 6 | 32.23 | 32.37 | 32.40 | 32.17 | 32.40 | 32.47 | 31.63 | 32.07 | 31.67 | 32.30 | 32.13 | 32.27 | 32.30 | 31.90 | 32.50 |
| 8 | 32.27 | 32.43 | 32.50 | 32.23 | 32.47 | 32.67 | 31.53 | 32.17 | 31.83 | 32.20 | 32.20 | 32.40 | 32.30 | 31.97 | 32.50 |
| 9 | 31.83 | 32.33 | 32.50 | 32.17 | 32.40 | 32.70 | 31.20 | 32.07 | 31.77 | 31.77 | 32.07 | 32.37 | 32.30 | 31.93 | 32.50 |
| 10 | 31.23 | 32.03 | 32.43 | 32.20 | 32.43 | 32.83 | 30.73 | 31.73 | 31.80 | 31.20 | 31.73 | 32.37 | 32.30 | 31.97 | 32.43 |
| 11 | 32.00 | 32.27 | 32.30 | 32.00 | 32.37 | 32.67 | 31.13 | 31.70 | 31.50 | 31.90 | 31.93 | 32.23 | 32.17 | 31.77 | 32.33 |
| 12 | 32.10 | 32.30 | 32.35 | 32.05 | 32.35 | 32.70 | 31.45 | 31.95 | 31.55 | 32.20 | 32.10 | 32.30 | 32.25 | 31.85 | 32.35 |
| 13 | 32.13 | 32.40 | 32.40 | 32.07 | 32.47 | 32.77 | 31.60 | 32.03 | 31.67 | 32.30 | 32.20 | 32.37 | 32.23 | 31.80 | 32.47 |
| 15 | 32.20 | 32.35 | 32.60 | 32.15 | 32.50 | 32.85 | 31.80 | 32.10 | 31.75 | 32.40 | 32.35 | 32.40 | 32.30 | 31.90 | 32.40 |
| 16 | 31.53 | 32.33 | 32.67 | 31.77 | 32.43 | 32.83 | 31.03 | 32.10 | 31.83 | 31.63 | 32.20 | 32.53 | 32.03 | 31.90 | 32.47 |
| 17 | 30.33 | 31.17 | 32.17 | 29.90 | 31.03 | 32.37 | 29.60 | 31.17 | 31.70 | 30.57 | 31.40 | 32.30 | 30.40 | 31.37 | 32.37 |
| 18 | 30.73 | 31.87 | 32.33 | 30.70 | 31.90 | 32.47 | 29.77 | 31.07 | 31.50 | 30.87 | 31.60 | 32.27 | 30.33 | 31.13 | 32.37 |
| 19 | 30.00 | 31.60 | 32.30 | 30.00 | 31.80 | 32.55 | 29.45 | 31.20 | 31.45 | 30.30 | 31.35 | 32.25 | 29.40 | 30.65 | 32.35 |
| 20 | 31.97 | 32.50 | 32.33 | 32.27 | 33.00 | 33.03 | 31.20 | 31.77 | 31.53 | 31.67 | 31.97 | 32.30 | 31.30 | 31.43 | 32.30 |
| 22 | 40.10 | 39.30 | 38.13 | 40.00 | 39.40 | 38.50 | 34.53 | 32.13 | 31.63 | 35.57 | 32.53 | 32.33 | 32.10 | 31.53 | 32.23 |
| 24 | 35.33 | 36.57 | 37.23 | 35.57 | 36.40 | 37.27 | 34.13 | 34.73 | 34.27 | 36.47 | 37.13 | 37.70 | 32.40 | 31.80 | 32.33 |
| 25 | 32.80 | 33.60 | 34.17 | 32.70 | 33.60 | 34.30 | 32.60 | 33.43 | 33.40 | 33.60 | 34.10 | 34.80 | 32.30 | 31.93 | 32.40 |
| 26 | 31.80 | 32.83 | 33.27 | 30.87 | 32.27 | 33.07 | 32.33 | 33.27 | 33.13 | 32.67 | 33.27 | 33.70 | 32.27 | 31.90 | 32.37 |
| 27 | 30.70 | 31.90 | 32.53 | 28.47 | 29.73 | 31.53 | 32.17 | 32.93 | 32.80 | 31.70 | 32.70 | 33.17 | 32.27 | 31.87 | 32.37 |
| Average | 32.21 | 32.74 | 32.96 | 32.19 | 32.73 | 33.13 | 31.49 | 32.13 | 31.95 | 32.11 | 32.31 | 32.73 | 31.93 | 31.74 | 32.40 |

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TABLE 28.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, MARCH, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 | 29.27 | 29.73 | 30.77 | 29.00 | 29.90 | 30.93 | 30.67 | 32.43 | 32.30 | 29.33 | 30.80 | 32.07 | 30.70 | 31.70 | 32.37 |
| 2 | 31.50 | 32.07 | 32.20 | 32.10 | 32.27 | 32.37 | 31.47 | 32.37 | 32.27 | 31.40 | 31.57 | 32.13 | 31.87 | 31.67 | 32.33 |
| 3 | 28.30 | 29.67 | 30.47 | 29.07 | 30.33 | 31.70 | 29.10 | 32.10 | 32.03 | 28.97 | 30.47 | 31.67 | 29.37 | 30.60 | 32.37 |
| 4 | 29.47 | 30.37 | 30.20 | 29.83 | 30.77 | 31.80 | 29.63 | 31.83 | 31.90 | 29.53 | 30.43 | 31.43 | 29.93 | 30.60 | 32.27 |
| 5 | 30.50 | 31.13 | 31.43 | 31.13 | 31.97 | 32.33 | 29.97 | 31.53 | 31.60 | 30.57 | 31.07 | 31.60 | 30.73 | 31.00 | 32.23 |
| 6 | 31.63 | 32.03 | 32.07 | 31.77 | 32.13 | 32.33 | 31.07 | 31.80 | 31.60 | 31.43 | 31.53 | 31.83 | 31.63 | 31.13 | 32.17 |
| 8 | 32.03 | 32.23 | 32.30 | 31.90 | 32.23 | 32.33 | 31.43 | 31.03 | 31.73 | 31.70 | 31.90 | 32.07 | 31.80 | 31.87 | 32.20 |
| 9 | 31.47 | 31.90 | 32.30 | 30.83 | 31.70 | 32.30 | 31.43 | 32.07 | 31.70 | 31.57 | 31.67 | 32.07 | 31.60 | 31.47 | 32.17 |
| 10 | 32.07 | 32.33 | 32.27 | 31.87 | 32.23 | 32.33 | 31.83 | 32.17 | 31.73 | 32.33 | 32.07 | 32.17 | 32.17 | 31.57 | 32.13 |
| 11 | 32.13 | 32.40 | 32.30 | 32.23 | 32.30 | 32.43 | 31.90 | 32.17 | 31.80 | 32.40 | 32.27 | 32.20 | 32.20 | 31.63 | 32.13 |
| 12 | 34.27 | 34.37 | 34.10 | 34.63 | 34.63 | 34.63 | 31.57 | 32.13 | 31.83 | 32.70 | 32.27 | 32.17 | 32.13 | 31.63 | 32.13 |
| 13 | 38.73 | 37.33 | 36.17 | 37.73 | 36.63 | 36.10 | 34.40 | 33.90 | 32.70 | 34.40 | 33.27 | 32.40 | 32.13 | 31.63 | 32.13 |
| 15 | 38.10 | 37.73 | 37.23 | 37.93 | 37.67 | 37.30 | 37.40 | 37.03 | 36.00 | 37.60 | 36.90 | 36.50 | 32.80 | 31.67 | 32.17 |
| 16 | 35.90 | 35.97 | 35.67 | 36.33 | 36.20 | 36.07 | 35.00 | 35.53 | 35.00 | 35.77 | 35.53 | 35.53 | 32.37 | 31.70 | 32.17 |
| 17 | 34.00 | 34.23 | 34.73 | 34.87 | 34.87 | 35.37 | 32.70 | 34.47 | 34.07 | 33.47 | 34.17 | 34.40 | 32.20 | 31.77 | 32.20 |
| 18 | 38.30 | 37.13 | 36.20 | 38.70 | 37.87 | 36.93 | 35.50 | 35.63 | 34.70 | 35.63 | 35.37 | 35.17 | 32.17 | 31.67 | 32.17 |
| 19 | 39.27 | 38.37 | 37.47 | 39.50 | 38.80 | 37.97 | 37.87 | 37.17 | 35.97 | 38.00 | 36.77 | 36.30 | 32.23 | 31.70 | 32.17 |
| 20 | 40.00 | 38.97 | 38.00 | 39.63 | 39.13 | 38.30 | 38.57 | 37.40 | 36.27 | 38.67 | 37.50 | 36.97 | 32.47 | 31.70 | 32.20 |
| 22 | 36.03 | 35.77 | 35.53 | 36.00 | 35.83 | 35.73 | 34.43 | 34.70 | 34.17 | 35.60 | 35.23 | 35.13 | 32.27 | 31.80 | 32.23 |
| 23 | 40.43 | 39.27 | 38.13 | 40.43 | 39.47 | 38.43 | 37.93 | 36.87 | 35.47 | 38.43 | 37.13 | 36.37 | 32.37 | 31.70 | 32.27 |
| 24 | 40.30 | 39.37 | 38.30 | 40.03 | 39.33 | 38.40 | 38.03 | 37.07 | 35.80 | 38.57 | 37.40 | 36.83 | 32.83 | 31.73 | 32.23 |
| 25 | 39.93 | 40.30 | 40.07 | 40.10 | 40.43 | 40.43 | 39.17 | 39.20 | 38.10 | 39.87 | 39.43 | 39.00 | 33.67 | 31.67 | 32.20 |
| 26 | 33.47 | 34.50 | 35.33 | 33.47 | 34.43 | 35.53 | 32.07 | 34.37 | 34.53 | 37.87 | 34.80 | 35.53 | 32.27 | 31.90 | 32.30 |
| 27 | 35.70 | 34.83 | 35.17 | 35.43 | 34.80 | 35.43 | 32.80 | 33.87 | 33.63 | 33.87 | 34.40 | 34.50 | 31.83 | 31.80 | 32.27 |
| 29 | 30.27 | 31.70 | 32.50 | 29.83 | 31.33 | 32.63 | 30.67 | 32.43 | 32.70 | 31.60 | 32.70 | 33.50 | 31.20 | 31.97 | 32.33 |
| 30 | 31.33 | 31.67 | 32.00 | 30.23 | 31.03 | 31.97 | 30.20 | 31.60 | 32.03 | 30.70 | 31.97 | 32.50 | 31.60 | 31.77 | 32.30 |
| 31 | 32.60 | 32.53 | 32.70 | 32.63 | 32.77 | 33.23 | 31.50 | 32.13 | 32.03 | 32.17 | 32.30 | 32.60 | 31.80 | 31.83 | 32.30 |
| Average | 34.33 | 34.37 | 34.28 | 34.34 | 34.48 | 34.64 | 33.27 | 33.89 | 33.47 | 33.86 | 33.74 | 33.88 | 31.86 | 31.59 | 32.23 |

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TABLE 29.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, APRIL, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 | 37.47 | 36.77 | 35.83 | 38.13 | 37.53 | 36.70 | 33.53 | 32.53 | 32.17 | 34.20 | 33.20 | 33.10 | 32.13 | 31.67 | 32.30 |
| 2 | 39.13 | 38.63 | 37.43 | 39.27 | 38.93 | 38.30 | 37.77 | 36.63 | 34.80 | 37.90 | 36.63 | 35.63 | 32.17 | 31.70 | 32.30 |
| 3 | 39.50 | 38.50 | 37.47 | 39.20 | 38.50 | 37.67 | 37.83 | 36.87 | 35.57 | 37.83 | 36.67 | 36.20 | 32.20 | 31.73 | 32.33 |
| 5 | 43.10 | 42.17 | 41.03 | 43.40 | 42.60 | 41.50 | 43.00 | 40.57 | 38.77 | 41.87 | 40.43 | 39.43 | 32.67 | 31.67 | 32.30 |
| 6 | 50.67 | 47.77 | 45.10 | 51.07 | 48.83 | 46.00 | 48.30 | 44.57 | 41.23 | 47.27 | 44.17 | 42.10 | 36.73 | 31.67 | 32.33 |
| 7 | 53.73 | 51.03 | 48.47 | 53.60 | 51.47 | 49.07 | 51.37 | 47.83 | 44.63 | 50.37 | 47.37 | 45.40 | 38.53 | 31.70 | 32.37 |
| 8 | 53.73 | 50.97 | 48.73 | 52.67 | 50.60 | 48.57 | 51.13 | 48.07 | 45.50 | 49.87 | 47.20 | 45.90 | 37.73 | 31.70 | 32.40 |
| 9 | 51.50 | 49.77 | 48.60 | 51.27 | 49.90 | 48.73 | 49.90 | 48.10 | 46.33 | 48.90 | 47.50 | 46.73 | 38.07 | 32.53 | 32.80 |
| 10 | 51.90 | 51.30 | 50.37 | 52.07 | 51.57 | 50.80 | 51.43 | 50.20 | 48.20 | 53.17 | 49.63 | 49.07 | 44.17 | 36.93 | 35.40 |
| 12 | 38.83 | 39.57 | 40.20 | 38.43 | 39.17 | 39.87 | 39.27 | 40.43 | 40.67 | 40.03 | 40.63 | 41.47 | 39.23 | 39.77 | 41.00 |
| 13 | 47.93 | 45.90 | 43.97 | 48.83 | 46.90 | 44.63 | 46.73 | 44.00 | 41.50 | 45.57 | 43.20 | 41.80 | 44.53 | 40.77 | 40.40 |
| 14 | 53.60 | 50.43 | 47.83 | 53.77 | 51.50 | 48.93 | 50.47 | 47.13 | 44.30 | 50.37 | 47.13 | 45.27 | 47.90 | 43.83 | 42.77 |
| 15 | 55.37 | 53.47 | 50.67 | 55.57 | 53.83 | 51.77 | 53.37 | 50.27 | 46.77 | 52.57 | 49.73 | 47.87 | 49.73 | 45.70 | 44.33 |
| 16 | 51.00 | 50.17 | 49.60 | 51.10 | 50.80 | 50.13 | 50.13 | 49.37 | 47.60 | 49.90 | 48.70 | 48.43 | 49.10 | 47.23 | 46.77 |
| 17 | 57.70 | 54.80 | 51.30 | 57.90 | 55.60 | 52.43 | 55.97 | 51.27 | 47.03 | 54.03 | 50.27 | 47.70 | 51.20 | 46.07 | 44.87 |
| 19 | 65.00 | 61.87 | 58.50 | 64.97 | 62.57 | 59.53 | 63.40 | 58.57 | 53.67 | 61.73 | 57.73 | 54.70 | 57.27 | 51.60 | 49.13 |
| 20 | 64.77 | 62.33 | 59.83 | 64.40 | 62.63 | 63.73 | 57.43 | 60.30 | 56.13 | 62.10 | 59.10 | 56.87 | 57.97 | 53.93 | 51.70 |
| 21 | 57.17 | 56.63 | 55.63 | 56.83 | 56.20 | 55.67 | 57.13 | 56.00 | 53.73 | 55.77 | 54.47 | 53.67 | 52.47 | 51.27 | 51.13 |
| 22 | 61.67 | 59.10 | 56.67 | 62.20 | 60.03 | 57.50 | 60.53 | 57.00 | 53.63 | 59.20 | 56.30 | 54.27 | 57.23 | 52.97 | 51.40 |
| 23 | 65.77 | 69.10 | 64.83 | 66.27 | 70.27 | 66.43 | 71.83 | 65.67 | 59.73 | 69.53 | 64.90 | 60.87 | 67.07 | 60.33 | 55.87 |
| 24 | 76.43 | 73.17 | 69.23 | 76.23 | 73.67 | 70.33 | 75.97 | 70.17 | 64.33 | 73.33 | 68.67 | 65.30 | 70.10 | 64.30 | 60.27 |
| 26 | 76.87 | 74.57 | 71.67 | 76.20 | 74.23 | 71.83 | 76.87 | 72.73 | 67.87 | 74.50 | 70.57 | 68.40 | 71.43 | 67.13 | 64.23 |
| 27 | 74.77 | 73.10 | 70.80 | 74.17 | 52.60 | 70.70 | 75.33 | 71.93 | 67.77 | 73.20 | 69.13 | 68.10 | 69.90 | 68.50 | 64.60 |
| 28 | 72.93 | 72.60 | 70.33 | 73.47 | 72.10 | 70.30 | 74.70 | 71.73 | 67.63 | 72.43 | 69.67 | 68.00 | 69.83 | 66.63 | 64.77 |
| 29 | 66.10 | 66.50 | 66.00 | 66.63 | 66.30 | 66.03 | 67.67 | 67.30 | 64.97 | 65.23 | 64.60 | 64.60 | 63.57 | 63.37 | 63.53 |
| 30 | 53.63 | 55.23 | 56.67 | 54.23 | 55.17 | 56.60 | 55.43 | 57.43 | 57.87 | 53.83 | 55.27 | 56.80 | 54.40 | 56.70 | 59.50 |
| Average | 56.16 | 54.82 | 52.95 | 56.22 | 54.36 | 53.60 | 55.25 | 52.95 | 50.10 | 54.41 | 52.03 | 50.69 | 49.90 | 48.59 | 45.80 |

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TABLE 30.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, MAY, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 | 58.53 | 57.23 | 55.93 | 58.03 | 56.97 | 56.03 | 58.43 | 56.97 | 55.00 | 56.73 | 55.03 | 54.60 | 56.60 | 54.93 | 55.83 |
| 3 | 52.60 | 53.93 | 54.73 | 52.73 | 53.70 | 54.83 | 53.77 | 55.33 | 55.37 | 53.13 | 53.10 | 54.87 | 53.57 | 54.83 | 56.77 |
| 4 | 48.53 | 49.80 | 50.57 | 46.27 | 49.07 | 50.07 | 49.90 | 51.17 | 51.13 | 49.73 | 49.70 | 51.17 | 50.60 | 51.50 | 53.40 |
| 5 | 53.33 | 52.93 | 52.30 | 53.63 | 53.27 | 52.70 | 53.33 | 52.73 | 51.00 | 53.20 | 51.53 | 51.57 | 53.83 | 52.13 | 52.13 |
| 6 | 59.40 | 57.80 | 55.93 | 60.80 | 59.23 | 57.37 | 57.97 | 55.57 | 52.83 | 58.17 | 55.43 | 54.17 | 54.53 | 54.40 | 53.07 |
| 7 | 55.63 | 56.00 | 56.00 | 56.53 | 56.53 | 56.60 | 56.13 | 55.90 | 54.33 | 56.03 | 55.77 | 55.47 | 56.70 | 55.93 | 55.30 |
| 8 | 52.30 | 53.07 | 53.17 | 52.83 | 53.33 | 53.63 | 52.70 | 52.97 | 51.87 | 52.93 | 52.17 | 52.77 | 53.70 | 53.13 | 53.47 |
| 10 | 60.43 | 57.67 | 54.90 | 61.67 | 59.37 | 56.67 | 56.90 | 53.97 | 50.80 | 57.10 | 53.90 | 52.07 | 53.77 | 52.43 | 50.83 |
| 11 | 66.70 | 63.63 | 60.50 | 67.07 | 64.77 | 61.77 | 64.07 | 59.57 | 55.27 | 62.93 | 58.40 | 56.50 | 60.73 | 56.07 | 53.77 |
| 12 | 70.43 | 67.63 | 64.53 | 70.53 | 68.40 | 65.73 | 68.17 | 64.20 | 59.87 | 67.07 | 63.17 | 60.67 | 64.27 | 59.80 | 57.00 |
| 13 | 67.13 | 65.17 | 63.30 | 66.73 | 65.20 | 63.80 | 65.10 | 63.43 | 60.47 | 64.70 | 62.10 | 60.93 | 63.50 | 60.20 | 58.67 |
| 14 | 69.23 | 67.17 | 64.37 | 68.43 | 66.70 | 64.63 | 66.77 | 63.87 | 60.87 | 69.37 | 62.60 | 61.00 | 63.30 | 60.20 | 58.57 |
| 15 | 62.53 | 61.60 | 60.67 | 61.60 | 61.23 | 60.30 | 60.77 | 60.60 | 58.90 | 60.07 | 58.57 | 58.50 | 58.23 | 57.07 | 57.70 |
| 17 | 49.67 | 50.23 | 50.57 | 50.20 | 50.33 | 50.57 | 49.43 | 51.07 | 50.77 | 50.47 | 50.27 | 51.00 | 50.73 | 50.87 | 52.47 |
| 18 | 48.03 | 47.90 | 48.13 | 47.73 | 47.67 | 47.63 | 47.30 | 48.10 | 47.77 | 48.30 | 47.43 | 48.20 | 48.23 | 47.77 | 49.57 |
| 19 | 57.67 | 55.17 | 52.80 | 58.53 | 56.33 | 54.10 | 54.00 | 52.00 | 49.40 | 54.73 | 50.90 | 50.30 | 54.20 | 50.40 | 49.30 |
| 20 | 48.90 | 49.53 | 50.00 | 48.77 | 49.27 | 49.90 | 47.77 | 49.67 | 49.23 | 48.87 | 48.23 | 49.63 | 49.00 | 49.20 | 50.60 |
| 21 | 61.10 | 59.40 | 57.17 | 62.77 | 61.17 | 58.97 | 58.87 | 56.37 | 52.90 | 59.60 | 56.10 | 54.43 | 59.70 | 54.67 | 52.03 |
| 22 | 56.93 | 56.13 | 58.80 | 57.67 | 56.77 | 56.10 | 55.43 | 54.50 | 52.97 | 55.27 | 53.03 | 53.93 | 55.47 | 53.97 | 53.70 |
| 24 | 62.97 | 64.70 | 62.70 | 67.30 | 65.67 | 53.87 | 54.93 | 62.13 | 58.83 | 63.80 | 61.03 | 59.57 | 63.47 | 63.07 | 57.37 |
| 25 | 62.70 | 62.17 | 61.40 | 62.97 | 62.47 | 61.90 | 62.13 | 61.13 | 58.97 | 61.53 | 60.10 | 59.60 | 61.63 | 59.63 | 58.50 |
| 26 | 57.77 | 57.93 | 57.93 | 58.43 | 58.53 | 58.37 | 57.47 | 57.67 | 56.70 | 57.33 | 56.87 | 57.27 | 58.20 | 57.57 | 57.97 |
| 27 | 57.60 | 56.27 | 55.00 | 57.10 | 56.10 | 55.00 | 55.57 | 54.23 | 52.23 | 55.13 | 53.27 | 52.60 | 55.63 | 52.93 | 53.53 |
| 28 | 56.03 | 56.20 | 54.97 | 52.40 | 55.17 | 55.03 | 54.83 | 54.17 | 52.70 | 54.47 | 53.10 | 53.17 | 54.40 | 53.10 | 53.67 |
| 29 | 55.37 | 55.40 | 55.17 | 55.87 | 55.57 | 55.33 | 55.13 | 54.87 | 53.40 | 55.17 | 54.27 | 54.10 | 55.87 | 54.23 | 54.27 |
| 31 | 70.40 | 67.23 | 63.97 | 70.47 | 68.07 | 65.17 | 64.17 | 63.27 | 59.10 | 66.13 | 61.90 | 59.60 | 63.90 | 59.27 | 56.90 |
| Average | 58.54 | 57.77 | 56.76 | 58.74 | 58.11 | 56.78 | 56.96 | 56.37 | 54.34 | 57.39 | 55.31 | 54.92 | 56.69 | 54.97 | 54.48 |

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TABLE 31.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JUNE, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 | 70.63 | 68.70 | 66.23 | 70.70 | 69.13 | 67.03 | 68.87 | 65.83 | 62.00 | 67.40 | 64.03 | 62.23 | 62.00 | 61.37 | 59 17 |
| 2 | 61.10 | 61.83 | 62.20 | 61.00 | 61.53 | 62.10 | 61.30 | 62.10 | 61.03 | 60.70 | 60.43 | 61.07 | 61.13 | 60.57 | 60.53 |
| 3 | 59.40 | 59.47 | 59.33 | 59.30 | 59.30 | 59.30 | 58.67 | 59.43 | 58.17 | 59.63 | 58.53 | 58.77 | 60.03 | 58.90 | 59 03 |
| 4 | 73.50 | 70.30 | 66.70 | 74.23 | 71.63 | 68.47 | 70.47 | 66.47 | 61.97 | 70.10 | 65.20 | 63.03 | 69.07 | 63.47 | 60 50 |
| 5 | 75.07 | 72.37 | 69.43 | 75.00 | 72.90 | 70.50 | 73.27 | 69.30 | 64.97 | 71.97 | 67.97 | 65.30 | 69.10 | 64.93 | 62.77 |
| 7 | 70.07 | 71.83 | 71.27 | 71.93 | 71.80 | 71.63 | 72.50 | 71.63 | 69.47 | 71.77 | 70.67 | 69.90 | 71.23 | 69.67 | 67.63 |
| 8 | 64.27 | 64.23 | 63.43 | 66.13 | 64.90 | 64.03 | 64.27 | 64.03 | 62.43 | 64.63 | 63.23 | 63.17 | 65.73 | 63.70 | 63.67 |
| 9 | ..... | 61.17 | 61.07 | 61.77 | 61.23 | 61.17 | 61.13 | 61.43 | 60.47 | 61.10 | 60.33 | 60.90 | 62.43 | 61.60 | 62.47 |
| 10 | ..... | 57.63 | 57.77 | 57.23 | 57.07 | 57.30 | 57.10 | 57.97 | 57.27 | 57.27 | 56.87 | 57.50 | 57.23 | 57.50 | 59.13 |
| 11 | ..... | 66.90 | 64.00 | 71.27 | 68.70 | 65.87 | 67.87 | 64.27 | 60.53 | 67.70 | 63.87 | 61.60 | 68.30 | 62.57 | 60.40 |
| 12 | ..... | 70.37 | 67.63 | 73.33 | 71.33 | 68.93 | 71.17 | 67.80 | 63.67 | 70.33 | 66.70 | 64.40 | 69.57 | 64.90 | 62.77 |
| 14 | 66.17 | 65.43 | 64.67 | 66.60 | 65.50 | 64.97 | 64.90 | 64.40 | 62.80 | 65.13 | 63.90 | 63.70 | 65.30 | 63.90 | 63.87 |
| 15 | 67.33 | 66.37 | 64.83 | 69.03 | 67.50 | 65.63 | 66.40 | 64.87 | 62.50 | 67.03 | 64.17 | 63.47 | 67.50 | 63.90 | 63.20 |
| 16 | 62.70 | 63.70 | 64.17 | 63.10 | 63.70 | 64.53 | 62.67 | 63.97 | 62.43 | 63.87 | 63.60 | 63.60 | 63.77 | 63.83 | 63.47 |
| 17 | 71.00 | 69.37 | 67.00 | 75.13 | 72.77 | 69.77 | 69.27 | 66.93 | 63.63 | 67.00 | 66.10 | 64.97 | 70.53 | 65.70 | 63.67 |
| 18 | 66.90 | 65.97 | 64.77 | 68.07 | 66.87 | 66.13 | 64.80 | 64.13 | 62.37 | 65.57 | 63.37 | 63.37 | 65.27 | 63.73 | 63.97 |
| 19 | 65.97 | 65.73 | 65.13 | 68.87 | 67.77 | 66.70 | 65.30 | 65.20 | 63.43 | 65.83 | 64.43 | 63.97 | 67.20 | 65.20 | 65.07 |
| 21 | 68.13 | 67.30 | 66.37 | 72.63 | 68.30 | 67.63 | 66.57 | 65.97 | 63.83 | 67.23 | 65.70 | 64.90 | 67.20 | 64.70 | 64.67 |
| 22 | 70.63 | 69.43 | 67.77 | 72.60 | 71.13 | 69.40 | 69.43 | 67.63 | 64.57 | 69.57 | 67.00 | 65.60 | 67.87 | 65.33 | 64.53 |
| 23 | 71.73 | 69.83 | 67.63 | 72.63 | 70.67 | 68.63 | 70.80 | 67.77 | 64.33 | 69.60 | 66.63 | 64.77 | 69.50 | 64.67 | 63.37 |
| 24 | 66.47 | 65.47 | 64.73 | 66.67 | 65.57 | 64.87 | 65.43 | 64.80 | 63.27 | 65.03 | 63.23 | 63.47 | 64.33 | 62.90 | 63.40 |
| 25 | 75.13 | 72.23 | 69.10 | 75.30 | 72.83 | 69.87 | 72.93 | 69.10 | 64.90 | 72.43 | 68.03 | 65.47 | 72.60 | 65.90 | 63.70 |
| 26 | 79.50 | 76.47 | 73.20 | 78.40 | 76.10 | 73.60 | 76.73 | 73.03 | 68.37 | 76.07 | 71.97 | 68.93 | 75.47 | 69.57 | 66.30 |
| 28 | 81.50 | 78.70 | 75.90 | 79.43 | 77.47 | 75.47 | 78.90 | 75.87 | 71.87 | 78.20 | 74.67 | 72.37 | 76.23 | 71.97 | 69.63 |
| 29 | 70.10 | 69.60 | 69.50 | 69.93 | 69.50 | 69.40 | 68.33 | 69.77 | 68.80 | 69.43 | 68.73 | 68.87 | 69.37 | 68.33 | 69.00 |
| 30 | 77.77 | 75.30 | 72.83 | 79.17 | 77.00 | 74.53 | 75.17 | 73.20 | 69.30 | 76.00 | 72.67 | 70.33 | 77.60 | 71.87 | 68.80 |
| Average | c69.78 | 67.92 | 66.79 | 69.98 | 68.55 | 67.22 | 67.86 | 66.42 | 63.79 | 67.84 | 65.46 | 64.45 | 67.53 | 64.65 | 63.66 |

cThe average of 22 days only instead of 26 on which remaining depths and soils were taken.

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TABLE 32.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JULY, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 | 77.57 | 75.93 | 74.60 | 77.70 | 76.50 | 75.60 | 75.27 | 74.90 | 71.77 | 76.60 | 74.00 | 72.63 | 75.33 | 74.13 | 72.37 |
| 2 | 74.77 | 73.90 | 72.77 | 77.77 | 76.33 | 74.77 | 73.23 | 72.97 | 70.50 | 75.03 | 72.63 | 71.70 | 74.97 | 72.20 | 71.17 |
| 3 | 75.97 | 73.93 | 72.27 | 76.73 | 75.17 | 73.63 | 72.00 | 71.87 | 69.27 | 73.77 | 71.10 | 70.47 | 72.60 | 70.93 | 70.47 |
| 5 | 62.20 | 62.50 | 63.00 | 63.20 | 63.45 | 63.70 | 60.25 | 63.25 | 62.75 | 63.30 | 62.90 | 63.75 | 61.90 | 63.20 | 64 90 |
| 6 | 71.47 | 69.43 | 67.20 | 72.63 | 70.77 | 68.73 | 66.70 | 66.70 | 63.77 | 70.10 | 66.57 | 65.40 | 66.67 | 63.93 | 63.53 |
| 7 | 64.83 | 64.97 | 65.40 | 64.53 | 64.53 | 65.30 | 61.33 | 65.10 | 64.27 | 64.83 | 64.13 | 65.43 | 64.03 | 64.50 | 65.13 |
| 8 | 71.10 | 69.30 | 67.43 | 74.10 | 72.17 | 69.83 | 67.30 | 67.77 | 64.67 | 69.70 | 66.47 | 65.80 | 69.03 | 65.43 | 64 17 |
| 9 | 78.63 | 75.47 | 72.27 | 79.67 | 77.20 | 74.63 | 73.50 | 72.07 | 67.77 | 73.87 | 69.47 | 68.17 | 72.63 | 68.07 | 65 77 |
| 10 | 81.43 | 78.87 | 76.17 | 81.57 | 79.60 | 77.43 | 78.30 | 75.50 | 71.30 | 76.87 | 73.93 | 71.40 | 76.97 | 71.90 | 69.03 |
| 12 | 83.73 | 81.20 | 78.50 | 83.43 | 81.53 | 79.37 | 81.03 | 78.30 | 74.33 | 79.70 | ..... | 74.30 | 81.00 | 75.30 | 73 07 |
| 13 | 85.90 | 82.83 | 79.67 | 84.57 | 82.53 | 80.23 | 83.00 | 79.70 | 75.50 | 81.03 | ..... | 75.33 | 82.53 | 77.03 | 74.47 |
| 14 | 81.60 | 80.10 | 78.43 | 81.03 | 79.90 | 78.57 | 78.67 | 78.37 | 75.47 | 78.40 | ..... | 75.10 | 80.03 | 76.93 | 75.57 |
| 15 | 75.23 | 74.70 | 74.37 | 75.23 | 74.90 | 74.70 | 73.33 | 74.87 | 73.03 | 75.13 | ..... | 73.53 | 76.30 | 74.90 | 74.30 |
| 16 | 80.43 | 78.47 | 76.57 | 82.13 | 80.33 | 78.23 | 77.53 | 77.10 | 73.83 | 80.30 | 77.33 | 75.10 | 80.73 | 76.50 | 74.57 |
| 17 | 84.70 | 82.07 | 79.43 | 85.07 | 83.30 | 80.97 | 81.13 | 79.67 | 75.77 | 82.13 | 79.10 | 76.80 | 82.97 | 78.27 | 75.90 |
| 19 | 73.63 | 73.57 | 73.00 | 74.27 | 74.03 | 73.47 | 72.20 | 73.60 | 71.80 | 75.47 | 73.90 | 72.90 | 75.13 | 73.60 | 73.50 |
| 20 | 73.23 | 71.77 | 70.80 | 73.77 | 72.43 | 71.50 | 70.73 | 71.27 | 69.40 | 73.47 | 71.90 | 71.03 | 71.60 | 70.67 | 70.93 |
| 21 | 69.37 | 70.27 | 70.17 | 68.97 | 69.80 | 70.43 | 68.40 | 70.53 | 68.63 | 70.27 | 70.30 | 69.67 | 69.83 | 68.97 | 69.03 |
| 22 | 75.37 | 72.97 | 71.07 | 76.10 | 74.07 | 72.07 | 72.67 | 71.73 | 68.50 | 74.67 | 72.00 | 69.83 | 72.93 | 69.73 | 67.57 |
| 23 | 80.63 | 77.80 | 75.10 | 80.77 | 78.80 | 76.40 | 77.03 | 75.03 | 71.23 | 77.23 | 74.37 | 72.17 | 77.00 | 72.30 | 70.20 |
| 24 | 75.23 | 74.33 | 73.40 | 75.23 | 74.60 | 74.00 | 72.80 | 73.07 | 70.87 | 73.10 | 72.07 | 71.20 | 73.33 | 71.57 | 70.87 |
| 26 | 75.73 | 73.73 | 72.23 | 76.77 | 75.13 | 73.53 | 73.67 | 72.67 | 70.07 | 75.17 | 72.93 | 71.43 | 74.90 | 71.93 | 70.23 |
| 27 | 68.30 | 68.43 | 68.60 | 68.03 | 68.23 | 68.67 | 67.27 | 68.87 | 67.97 | 68.43 | 68.47 | 68.70 | 68.63 | 68.77 | 69.50 |
| 28 | 71.07 | 70.27 | 69.67 | 71.10 | 70.60 | 70.23 | 69.50 | 69.90 | 68.13 | 70.67 | 69.73 | 69.00 | 71.23 | 69.77 | 68.60 |
| 29 | 72.53 | 71.00 | 69.60 | 72.40 | 71.20 | 70.20 | 70.73 | 69.93 | 67.80 | 71.87 | 69.87 | 68.90 | 72.27 | 69.53 | 68.30 |
| 30 | 79.33 | 77.33 | 75.43 | 80.40 | 78.70 | 76.90 | 76.97 | 75.53 | 72.17 | 78.97 | 76.13 | 73.87 | 79.43 | 75.17 | 69.93 |
| 31 | 80.07 | 77.73 | 75.70 | 79.87 | 78.20 | 76.63 | 77.60 | 75.93 | 72.80 | 78.77 | 76.20 | 74.37 | 79.57 | 75.60 | 71.43 |
| Average | 75.70 | 74.18 | 72.70 | 76.18 | 74.96 | 73.69 | 73.41 | 72.82 | 70.12 | 74.39 | c71.55 | 71.04 | 74.20 | 71.51 | 70.16 |

cAverage of 23 days only.

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TABLE 33.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, AUGUST, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 2 | 73.63 | 73.10 | 73.37 | 73.00 | 72.63 | 73.23 | 72.57 | 73.50 | 72.93 | 73.17 | 73.33 | 73.77 | 74.00 | 74.53 | 75.17 |
| 3 | 72.47 | 71.67 | 71.00 | 72.27 | 71.67 | 71.27 | 71.63 | 71.30 | 69.73 | 72.60 | 71.33 | 70.47 | 73.17 | 71.77 | 72.03 |
| 4 | 68.70 | 68.50 | 68.40 | 68.77 | 68.67 | 68.73 | 68.00 | 68.67 | 67.77 | 69.07 | 68.63 | 68.73 | 69.33 | 69.37 | 70.27 |
| 5 | 62.20 | 62.77 | 63.63 | 61.70 | 62.30 | 63.33 | 61.77 | 63.83 | 64.00 | 62.87 | 63.73 | 64.70 | 62.93 | 64.77 | 67.00 |
| 6 | 67.53 | 66.37 | 65.57 | 67.67 | 66.73 | 65.97 | 65.97 | 65.57 | 63.87 | 67.07 | 65.63 | 64.87 | 66.97 | 65.20 | 65.30 |
| 7 | 68.33 | 67.10 | 66.23 | 68.43 | 67.80 | 67.03 | 66.43 | 66.03 | 64.20 | 67.47 | 66.20 | 65.33 | 67.57 | 65.50 | 64.37 |
| 9 | 77.97 | 75.50 | 73.23 | 79.30 | 77.23 | 74.97 | 73.90 | 71.80 | 68.67 | 76.43 | 73.37 | 71.10 | 76.43 | 71.57 | 69.30 |
| 10 | 80.33 | 78.03 | 75.60 | 81.03 | 79.17 | 77.07 | 76.37 | 74.10 | 70.60 | 78.43 | 75.37 | 72.93 | 78.63 | 73.17 | 70.67 |
| 11 | 69.03 | 69.20 | 69.87 | 68.53 | 68.73 | 69.53 | 67.40 | 68.80 | 68.33 | 68.63 | 68.97 | 69.53 | 68.30 | 68.97 | 70.40 |
| 12 | 66.93 | 66.87 | 67.13 | 66.77 | 66.70 | 66.93 | 66.20 | 67.03 | 66.23 | 67.23 | 67.03 | 67.17 | 67.20 | 67.03 | 67.87 |
| 13 | 73.00 | 71.43 | 70.17 | 74.07 | 72.73 | 71.37 | 70.87 | 69.80 | 67.33 | 71.93 | 70.00 | 68.63 | 71.87 | 68.97 | 67.40 |
| 14 | 70.17 | 69.33 | 68.80 | 70.30 | 69.80 | 69.37 | 68.83 | 68.67 | 67.00 | 69.73 | 68.70 | 68.13 | 69.80 | 68.23 | 67.47 |
| 16 | 76.60 | 74.90 | 73.20 | 77.77 | 76.33 | 74.67 | 73.73 | 72.30 | 69.63 | 74.87 | 72.60 | 70.93 | 74.90 | 71.43 | 68.87 |
| 17 | 68.83 | 68.60 | 68.63 | 70.30 | 69.70 | 69.53 | 67.70 | 68.53 | 67.50 | 68.83 | 68.53 | 68.50 | 68.43 | 68.30 | 68.77 |
| 18 | 71.80 | 69.73 | 68.03 | 72.90 | 71.27 | 69.50 | 68.67 | 67.47 | 65.10 | 69.07 | 67.07 | 65.90 | 68.33 | 65.77 | 68.47 |
| 19 | 76.03 | 73.47 | 71.20 | 76.57 | 74.87 | 72.73 | 72.87 | 70.47 | 67.13 | 73.27 | 70.73 | 68.20 | 72.80 | 68.37 | 66.30 |
| 20 | 70.50 | 69.90 | 69.10 | 70.50 | 69.97 | 69.50 | 68.70 | 68.23 | 66.57 | 68.97 | 68.07 | 67.43 | 68.67 | 67.20 | 66.90 |
| 21 | 65.00 | 65.17 | 65.60 | 64.70 | 64.93 | 65.50 | 64.43 | 65.27 | 64.70 | 65.23 | 65.23 | 65.57 | 65.20 | 65.33 | 66.37 |
| 23 | 74.73 | 72.80 | 70.67 | 76.40 | 74.67 | 72.80 | 72.30 | 70.03 | 66.97 | 72.57 | 70.03 | 68.20 | 72.33 | 68.23 | 66.60 |
| 24 | 71.83 | 71.23 | 70.57 | 72.30 | 72.00 | 71.67 | 70.40 | 70.03 | 68.17 | 70.73 | 69.97 | 69.27 | 70.80 | 69.37 | 67.90 |
| 25 | 68.00 | 66.97 | 66.43 | 68.30 | 67.50 | 66.77 | 66.13 | 65.67 | 64.60 | 66.47 | 65.57 | 65.40 | 66.03 | 65.07 | 65.93 |
| 26 | 68.63 | 67.90 | 66.97 | 69.17 | 68.70 | 67.97 | 66.77 | 66.33 | 64.30 | 67.33 | 66.23 | 65.30 | 67.77 | 65.43 | 64.77 |
| 27 | 68.27 | 66.83 | 65.40 | 67.97 | 66.90 | 65.90 | 65.60 | 64.50 | 62.53 | 66.30 | 64.43 | 63.40 | 66.03 | 63.27 | 63.20 |
| 28 | 70.70 | 68.93 | 67.03 | 70.50 | 69.23 | 67.63 | 67.73 | 66.07 | 63.43 | 68.47 | 66.10 | 64.50 | 68.53 | 64.47 | 63.57 |
| 30 | 65.27 | 64.23 | 63.33 | 65.33 | 64.50 | 63.70 | 63.10 | 62.57 | 61.27 | 63.93 | 62.57 | 62.10 | 64.03 | 62.10 | 62.67 |
| 31 | 66.57 | 65.07 | 63.67 | 66.23 | 65.17 | 64.07 | 63.87 | 62.80 | 60.83 | 64.60 | 62.83 | 61.70 | 64.63 | 61.47 | 61.43 |
| Average | 70.50 | 69.45 | 68.58 | 70.80 | 70.00 | 69.28 | 68.54 | 68.06 | 66.28 | 69.44 | 68.17 | 67.38 | 69.42 | 67.50 | 67.28 |

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TABLE 34.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, SEPTEMBER, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 | 70.17 | 68.23 | 66.23 | 70.07 | 68.67 | 67.03 | 67.73 | 65.50 | 62.73 | 68.10 | 65.70 | 63.90 | 68.20 | 63.97 | 62.77 |
| 2 | 73.33 | 71.13 | 68.77 | 73.00 | 71.43 | 69.53 | 70.73 | 68.07 | 64.93 | 71.13 | 68.27 | 66.20 | 71.50 | 66.57 | 64.50 |
| 3 | 72.03 | 70.87 | 69.43 | 71.83 | 70.93 | 69.90 | 70.20 | 68.63 | 66.10 | 70.40 | 68.67 | 67.20 | 70.60 | 67.40 | 66.30 |
| 4 | 70.27 | 69.17 | 68.37 | 70.10 | 69.33 | 68.77 | 69.40 | 67.93 | 65.67 | 68.23 | 67.20 | 66.60 | 69.23 | 67.13 | 66.60 |
| 6 | 64.10 | 64.13 | 64.27 | 63.93 | 64.13 | 64.43 | 64.30 | 64.40 | 63.50 | 64.43 | 64.40 | 64.40 | 64.50 | 64.23 | 64.80 |
| 7 | 69.97 | 68.03 | 66.47 | 70.20 | 68.67 | 67.27 | 69.10 | 66.60 | 64.23 | 68.83 | 66.63 | 65.27 | 69.13 | 65.53 | 64.77 |
| 8 | 74.33 | 72.67 | 70.80 | 75.00 | 73.60 | 72.23 | 73.63 | 70.97 | 67.93 | 73.10 | 70.90 | 69.07 | 74.13 | 69.70 | 67.77 |
| 9 | 69.47 | 69.23 | 69.10 | 70.70 | 70.47 | 70.40 | 69.60 | 69.37 | 67.83 | 69.20 | 68.93 | 68.60 | 70.27 | 69.50 | 69.07 |
| 10 | 67.20 | 67.23 | 66.93 | 67.63 | 67.83 | 67.87 | 67.47 | 67.37 | 65.63 | 66.90 | 66.57 | 66.10 | 66.80 | 66.33 | 66.70 |
| 11 | 71.23 | 69.60 | 68.00 | 71.30 | 70.17 | 68.83 | 70.83 | 68.37 | 65.93 | 70.40 | 68.17 | 66.83 | 71.23 | 67.40 | 66.40 |
| 13 | 76.63 | 74.97 | 73.20 | 79.57 | 77.93 | 75.83 | 76.13 | 73.70 | 70.37 | 75.80 | 73.57 | 71.63 | 75.67 | 72.67 | 70.20 |
| 14 | 80.77 | 78.73 | 76.37 | 82.40 | 80.93 | 78.90 | 80.37 | 77.10 | 73.20 | 79.30 | 76.63 | 74.20 | 78.33 | 74.43 | 72.10 |
| 15 | 76.90 | 76.00 | 75.23 | 77.40 | 76.73 | 76.23 | 76.90 | 75.60 | 73.20 | 75.73 | 74.80 | 73.90 | 76.00 | 74.10 | 73.13 |
| 16 | 75.47 | 74.43 | 73.53 | 76.43 | 75.63 | 74.73 | 74.80 | 73.53 | 71.60 | 75.30 | 73.80 | 72.57 | 75.33 | 73.03 | 72.10 |
| 17 | 72.60 | 72.10 | 71.33 | 73.03 | 72.57 | 72.00 | 72.60 | 71.60 | 69.83 | 72.53 | 71.50 | 70.97 | 73.70 | 71.77 | 71.43 |
| 20 | 67.17 | 67.17 | 67.30 | 67.33 | 67.60 | 67.83 | 67.63 | 67.60 | 66.37 | 67.13 | 67.07 | 66.97 | 66.77 | 67.13 | 67.83 |
| 21 | 56.67 | 57.60 | 58.90 | 57.07 | 57.80 | 58.83 | 57.37 | 59.17 | 59.60 | 57.47 | 58.70 | 60.03 | 58.17 | 59.90 | 62.73 |
| 22 | 60.70 | 59.93 | 58.27 | 61.33 | 61.27 | 60.13 | 60.43 | 59.47 | 57.93 | 59.63 | 58.90 | 58.33 | 59.87 | 57.93 | 58.97 |
| 23 | 60.90 | 59.93 | 59.33 | 61.60 | 61.00 | 60.27 | 60.57 | 59.47 | 58.00 | 59.93 | 58.90 | 58.33 | 58.47 | 57.27 | 58.47 |
| 24 | 69.97 | 68.07 | 66.00 | 71.00 | 69.77 | 67.90 | 69.33 | 66.20 | 62.93 | 68.00 | 65.50 | 63.53 | 68.37 | 63.63 | 61.53 |
| 25 | 69.87 | 68.40 | 66.87 | 70.77 | 69.73 | 68.30 | 69.50 | 67.13 | 64.37 | 68.20 | 66.23 | 64.73 | 68.30 | 64.73 | 63.30 |
| 27 | 52.63 | 53.10 | 54.23 | 52.33 | 52.27 | 53.40 | 53.27 | 54.20 | 54.97 | 53.13 | 53.80 | 55.30 | 52.27 | 54.57 | 57.73 |
| 28 | 55.23 | 55.13 | 54.73 | 56.47 | 56.10 | 55.43 | 54.97 | 54.57 | 53.80 | 54.00 | 53.83 | 52.87 | 54.57 | 53.37 | 55.00 |
| 29 | 56.87 | 56.23 | 55.20 | 57.60 | 53.73 | 56.27 | 56.57 | 55.47 | 53.67 | 54.80 | 54.07 | 53.37 | 55.40 | 53.17 | 53.80 |
| 30 | 57.20 | 56.37 | 55.60 | 57.53 | 56.97 | 55.80 | 57.17 | 55.63 | 54.07 | 55.07 | 54.13 | 53.63 | 55.07 | 53.13 | 53.77 |
| **Average** | **67.67** | **66.74** | **65.78** | **68.23** | **67.41** | **66.73** | **67.22** | **65.90** | **63.94** | **66.67** | **65.47** | **64.58** | **66.88** | **64.74** | **64.47** |

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TABLE 35.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, OCTOBER, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 | 52.97 | 53.53 | 53.20 | 52.70 | 53.33 | 54.17 | 53.10 | 53.83 | 53.60 | 52.97 | 53.37 | 53.77 | 52.87 | 53.30 | 54.50 |
| 2 | 59.60 | 58.07 | 57.37 | 59.77 | 59.00 | 58.10 | 58.67 | 57.10 | 55.13 | 58.40 | 56.87 | 55.83 | 59.13 | 55.93 | 55.07 |
| 4 | 61.03 | 61.07 | 60.83 | 61.03 | 61.33 | 61.40 | 60.93 | 60.53 | 59.00 | 60.67 | 60.33 | 59.63 | 61.60 | 60.00 | 59.13 |
| 5 | 53.43 | 54.40 | 55.13 | 53.30 | 54.03 | 55.00 | 53.43 | 54.43 | 54.47 | 52.93 | 53.87 | 54.83 | 54.07 | 54.97 | 56.70 |
| 6 | 53.20 | 53.63 | 53.90 | 52.87 | 53.47 | 53.37 | 52.97 | 53.40 | 52.87 | 52.23 | 52.67 | 53.10 | 53.17 | 52.97 | 54.13 |
| 7 | 48.97 | 50.37 | 51.27 | 48.93 | 50.07 | 51.20 | 49.23 | 50.50 | 50.50 | 49.27 | 49.87 | 50.57 | 49.27 | 50.20 | 52.10 |
| 8 | 44.40 | 45.73 | 46.80 | 43.80 | 44.93 | 46.27 | 44.50 | 46.33 | 46.50 | 44.77 | 46.37 | 47.23 | 44.67 | 46.47 | 49.43 |
| 9 | 45.07 | 45.90 | 46.30 | 45.27 | 45.70 | 45.97 | 45.03 | 45.60 | 45.93 | 44.50 | 45.00 | 45.70 | 45.27 | 45.90 | 47.33 |
| 11 | 56.37 | 54.53 | 52.67 | 57.40 | 56.13 | 54.10 | 54.73 | 52.07 | 49.30 | 53.80 | 51.47 | 49.60 | 52.73 | 48.57 | 47.80 |
| 12 | 46.97 | 55.47 | 54.33 | 57.43 | 56.60 | 55.30 | 55.50 | 53.70 | 51.70 | 54.60 | 53.13 | 52.03 | 53.97 | 50.87 | 50.40 |
| 13 | 56.33 | 55.43 | 54.73 | 56.50 | 55.87 | 55.33 | 55.50 | 54.30 | 52.77 | 55.53 | 54.13 | 53.30 | 55.33 | 52.30 | 52.03 |
| 14 | 56.10 | 55.83 | 55.47 | 56.07 | 56.07 | 55.97 | 55.83 | 55.23 | 53.73 | 55.90 | 55.27 | 54.63 | 55.77 | 53.87 | 53.47 |
| 15 | 58.27 | 57.50 | 56.53 | 58.57 | 58.13 | 57.23 | 57.50 | 56.23 | 54.37 | 56.77 | 55.77 | 55.03 | 58.10 | 55.00 | 54.00 |
| 16 | 56.37 | 55.03 | 53.70 | 56.60 | 55.63 | 54.30 | 55.37 | 53.50 | 52.00 | 54.10 | 52.80 | 52.10 | 55.17 | 52.30 | 52.30 |
| 18 | 58.33 | 57.93 | 57.43 | 58.47 | 58.50 | 58.13 | 58.13 | 57.23 | 55.47 | 58.13 | 57.07 | 56.30 | 58.40 | 56.30 | 55.37 |
| 19 | 56.47 | 56.27 | 55.93 | 56.20 | 56.40 | 56.10 | 56.27 | 55.77 | 54.40 | 56.13 | 55.67 | 55.20 | 56.80 | 54.97 | 54.80 |
| 20 | 58.47 | 57.50 | 56.43 | 58.83 | 58.10 | 57.20 | 57.57 | 56.23 | 54.33 | 57.43 | 56.07 | 55.17 | 57.60 | 54.80 | 54.27 |
| 21 | 54.70 | 54.17 | 53.80 | 55.03 | 54.37 | 54.37 | 53.97 | 53.40 | 52.57 | 53.50 | 53.23 | 53.03 | 52.57 | 52.27 | 53.30 |
| 22 | 53.63 | 52.83 | 51.80 | 53.63 | 52.97 | 51.93 | 52.43 | 51.70 | 50.40 | 51.60 | 51.33 | 50.83 | 50.33 | 49.40 | 50.77 |
| 23 | 51.27 | 51.23 | 51.10 | 50.93 | 51.03 | 51.13 | 50.53 | 50.57 | 49.73 | 49.73 | 49.80 | 49.93 | 49.47 | 48.97 | 50.20 |
| 25 | 54.17 | 53.13 | 52.17 | 54.47 | 53.87 | 53.00 | 52.93 | 51.60 | 49.77 | 52.13 | 50.83 | 49.87 | 51.83 | 49.10 | 49.13 |
| 26 | 50.60 | 50.43 | 50.27 | 50.60 | 50.70 | 50.60 | 49.87 | 49.67 | 49.13 | 49.23 | 49.07 | 49.03 | 48.70 | 48.03 | 48.90 |
| 27 | 51.57 | 50.77 | 50.00 | 51.57 | 51.20 | 50.57 | 50.47 | 49.50 | 47.70 | 49.57 | 48.73 | 48.07 | 49.50 | 47.37 | 47.93 |
| 28 | 53.80 | 52.40 | 50.37 | 54.10 | 53.13 | 51.70 | 52.30 | 50.53 | 48.63 | 51.53 | 50.03 | 48.93 | 51.20 | 48.13 | 48.20 |
| 29 | 51.77 | 51.03 | 50.53 | 51.77 | 51.53 | 50.87 | 50.70 | 49.90 | 48.93 | 50.03 | 49.27 | 49.03 | 49.43 | 48.23 | 48.57 |
| 30 | 51.37 | 50.63 | 50.00 | 51.60 | 51.03 | 50.57 | 50.37 | 49.53 | 48.20 | 49.33 | 48.83 | 48.43 | 49.40 | 47.73 | 48.17 |
| Average | 53.66 | 53.85 | 53.16 | 54.13 | 53.97 | 53.61 | 53.38 | 52.78 | 51.58 | 52.88 | 52.34 | 51.97 | 52.94 | 51.46 | 51.85 |

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TABLE 36.—AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, NOVEMBER, 1915.

| Date. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 | 53.70 | 52.73 | 52.30 | 53.50 | 53.03 | 52.83 | 52.20 | 51.57 | 50.50 | 51.70 | 50.47 | 50.80 | 51.03 | 50.17 | 50.17 |
| 2 | 45.37 | 46.53 | 47.63 | 45.30 | 46.30 | 47.57 | 45.27 | 47.07 | 47.73 | 45.10 | 46.23 | 47.67 | 45.03 | 47.83 | 49.10 |
| 3 | 42.90 | 43.33 | 43.73 | 42.70 | 43.17 | 43.63 | 42.67 | 43.30 | 43.17 | 41.90 | 42.47 | 43.13 | 41.37 | 42.13 | 44.90 |
| 4 | 48.63 | 47.83 | 47.00 | 48.83 | 48.30 | 47.63 | 47.50 | 46.57 | 45.37 | 47.00 | 46.10 | 45.47 | 46.80 | 44.83 | 45.20 |
| 5 | 42.97 | 43.70 | 44.30 | 42.50 | 43.27 | 44.13 | 42.60 | 43.70 | 43.80 | 42.63 | 43.27 | 44.00 | 42.20 | 43.23 | 45.13 |
| 6 | 43.43 | 43.03 | 42.73 | 43.30 | 43.00 | 42.73 | 42.27 | 41.97 | 41.57 | 42.00 | 41.73 | 41.80 | 40.73 | 40.40 | 42.60 |
| 8 | 56.07 | 54.60 | 52.87 | 56.97 | 55.97 | 54.50 | 54.90 | 52.67 | 49.87 | 54.60 | 52.50 | 50.63 | 54.10 | 50.03 | 47.70 |
| 9 | 46.17 | 46.33 | 46.70 | 46.10 | 46.60 | 47.17 | 46.10 | 46.53 | 46.20 | 45.47 | 42.57 | 46.23 | 45.37 | 45.60 | 46.60 |
| 10 | 41.30 | 41.47 | 42.47 | 40.80 | 41.33 | 42.20 | 41.53 | 41.63 | 42.23 | 40.87 | 41.47 | 42.27 | 39.50 | 40.93 | 43.57 |
| 11 | 53.23 | 51.40 | 49.77 | 53.33 | 51.87 | 50.40 | 51.60 | 49.20 | 47.00 | 51.77 | 49.43 | 48.00 | 50.63 | 46.80 | 45.63 |
| 12 | 43.43 | 44.40 | 45.40 | 43.03 | 44.10 | 44.03 | 43.97 | 45.60 | 45.73 | 44.10 | 45.60 | 46.10 | 44.17 | 45.33 | 46.60 |
| 13 | 40.30 | 40.93 | 41.17 | 40.00 | 40.63 | 41.23 | 40.77 | 41.60 | 41.67 | 40.70 | 41.27 | 42.23 | 40.53 | 41.00 | 43.13 |
| 15 | 34.67 | 35.97 | 37.17 | 34.23 | 35.27 | 36.67 | 34.70 | 36.83 | 37.83 | 35.13 | 36.57 | 37.87 | 35.57 | 37.57 | 40.10 |
| 16 | 33.73 | 35.67 | 35.77 | 32.83 | 33.87 | 35.17 | 33.37 | 35.17 | 36.17 | 33.47 | 34.80 | 36.13 | 33.97 | 36.07 | 38.50 |
| 17 | 37.97 | 37.80 | 37.67 | 37.57 | 37.60 | 38.03 | 37.13 | 37.40 | 37.07 | 38.47 | 38.17 | 37.90 | 34.87 | 35.70 | 37.53 |
| 18 | 37.83 | 38.03 | 37.97 | 37.67 | 37.90 | 38.00 | 37.37 | 37.47 | 37.17 | 38.00 | 37.83 | 37.70 | 35.73 | 35.87 | 37.40 |
| 19 | 39.67 | 40.17 | 40.57 | 39.63 | 40.20 | 40.80 | 39.40 | 40.10 | 39.83 | 39.97 | 40.33 | 40.53 | 38.93 | 39.07 | 39.53 |
| 20 | 36.77 | 37.63 | 38.33 | 36.63 | 37.43 | 38.27 | 36.67 | 37.77 | 37.97 | 37.30 | 37.97 | 38.27 | 36.63 | 37.40 | 38.70 |
| 22 | 32.87 | 33.93 | 34.80 | 32.53 | 33.63 | 34.70 | 33.30 | 34.67 | 35.27 | 33.47 | 34.40 | 35.40 | 33.63 | 34.87 | 37.10 |
| 23 | 32.43 | 33.43 | 34.13 | 32.13 | 33.07 | 34.00 | 32.60 | 33.97 | 34.47 | 33.07 | 33.90 | 34.67 | 33.27 | 34.23 | 36.07 |
| 24 | 34.70 | 35.00 | 35.27 | 33.60 | 34.37 | 35.13 | 33.60 | 34.57 | 34.57 | 34.03 | 34.60 | 34.10 | 33.07 | 33.97 | 35.57 |
| 26 | 48.03 | 46.77 | 45.60 | 48.47 | 47.60 | 46.63 | 46.47 | 44.90 | 42.93 | 47.00 | 45.40 | 44.00 | 45.43 | 42.17 | 40.67 |
| 27 | 43.60 | 44.20 | 44.60 | 43.37 | 43.93 | 44.37 | 42.93 | 43.80 | 43.43 | 43.20 | 43.97 | 44.13 | 43.20 | 42.97 | 42.90 |
| 29 | 34.63 | 36.07 | 37.20 | 34.00 | 35.10 | 36.47 | 34.97 | 36.77 | 37.53 | 35.37 | 36.77 | 37.97 | 36.00 | 38.00 | 40.07 |
| 30 | 33.83 | 34.83 | 35.83 | 33.40 | 34.43 | 35.50 | 33.87 | 35.50 | 36.03 | 34.57 | 35.60 | 36.47 | 34.60 | 36.10 | 38.00 |
| Average | 41.37 | 41.67 | 41.87 | 41.14 | 41.52 | 41.91 | 40.95 | 41.45 | 41.25 | 41.07 | 41.18 | 41.58 | 40.50 | 40.73 | 41.94 |

The daily and monthly average temperature of the second year, December 1, 1912 to November 30, 1913, are contained in Tables 1 to 12, inclusive. Beginning with the data of the month of December it will readily be seen that at the commencement of the month all the various types of soil at the three different depths had practically the same magnitude of temperature and had not yet reached the freezing point. The temperature at all three depths in every soil diminished gradually until December 12 when the upper 6-inch depth began to freeze. At this date the 6-inch depth of only the sand and gravel froze, that of the loam and clay froze one day later and peat ten days later. It will be noted, however, that while the peat at the 6-inch depth froze ten days later than that of the other soils its temperature during this time was only a few tenths of a degree higher. The temperature at the 6-inch depth of all the soils remained at or slightly below 32°F until January 3, when it rose in all of them a few tenths of a degree but it fell again at or below 32°F on January 29. Between February 4 and 14 the temperature at the 6-inch depth of all soils was several degrees below zero and on February 13 reached its minimum for the winter. At this date the average temperature of the various soils at this upper depth was as follows: gravel 22.43°, sand 19.60°, loam 23.30°, clay 23.93°, and peat 20.50°F. It is of great interest, therefore, to note that all these diverse classes of soil had practically the same average temperature during this period of cold weather in spite of their great difference in heat conductivity, water content, etc.

The air temperature on February 13 when the lowest temperature was reached, was 3° F.

While the 6-inch depth of all the different types of soil began to freeze about Dec. 12 and its temperature tended to remain at or near the freezing point, the 12 and 18-inch depths of all these soils did not really begin to freeze until the commencement of February when the extreme cold weather came. The 12-inch depth of the gravel and sand froze February 3, that of loam, clay and peat on February 5, or two days later; while the 18-inch depth of the various soils froze as follows: gravel February 6, sand February 8, clay February 10, loam February 11, that of peat did not completely freeze, its temperature remaining a few tenths of a degree above 32° F. throughout the rest of the winter.

It is remarkable to note that the temperature of the 12-inch and as well as that of the 18-inch depths attained its minimum degree practically simultaneously with the 6-inch depths. Yet when this minimum was reached at all three depths the difference or gradient of temperature between the 6 and 18-inch depths was very marked, being in most cases close to 12°F. In other words, when the temperature of the 6-inch depth reached its lowest degree, and it was about 20° F, the corresponding minimum of the 18-inch depth, which occurred on the same day, was about 32°F, or a gradient of 12°F.

The temperature at the 6-inch depth remained considerably below 32°F from February 4 to 20 and then it rose and tended to stay at about 32°F. When the other two depths froze their temperature also tended to remain at about 32°F. Hence the upper 18-inch layer of the soil had almost the same temperature and consequently had no gradient.

The temperature of the entire upper 18-inch layer remained at the freezing point until thawing began. The first thawing occurred on March 19. At this date the gravel and sand thawed completely down to the 18-inch depth—in a single day—while only the 6-inch depth of the loam and clay thawed on this date and that of the peat did not show any signs of thawing. At the 12 and 18-inch depths only clay commenced to thaw by March 26. The process of thawing, however, was only of short duration as on March 26 the air temperature fell very low and the upper 6-inch depth began to freeze again. On March 31, however, the air temperature went up again and the soil temperature commenced to rise accordingly. On April 1 the 12-inch depth of the loam and the 6-inch depth of the peat began to thaw. The 12-inch depth of the peat did not show signs of thawing until April 15. The temperature of the 18-inch depth of the loam began to rise slightly above 32°F by March 8—long before the actual thawing at the surface of the various soils had taken place—so that by the time the other two depths had thawed it was by a few degrees higher than that of the 12-inch depth.

This rising of temperature at the 18-inch depth of the loam before complete thawing had taken place at the above depths is extremely interesting and goes to indicate that some heat comes to the surface from the lower and warmer depths of the earth. This fact finds confirmation in all the other soils and especially in peat. The 18-inch depth of the latter did not completely freeze but its temperature remained a few tenths of a degree above 32°F. By the middle of March, however, its temperature began to rise slowly but rather persistently so that by April 1, when the 6-inch depth of this soil commenced to thaw it was

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34°F and by April 15 when the 12-inch depth began to thaw it had risen to 36.43°F.

These instances therefore, prove conclusively that an appreciable amount of heat traverses to the surface from the lower depths and tends to maintain a higher temperature there than would otherwise exist. It is perhaps partly on this account that after the soils freeze at the upper depths their temperature tends to remain at about the freezing point. At least a portion of the heat they lose at these upper depths is replenished by the heat coming from the lower depths. In the spring, however, when the air temperature begins to rise and the loss of heat from the soil is thereby diminished if not entirely stopped, the heat coming from the interior of the earth accumulates near the upper depths and causes a rise in temperature, just as the experimental data show. The amount, however, coming to the surface during a single day is undoubtedly small, partly because of the low heat conductivity of the soil, and partly on account of the small gradient of temperature existing at the adjacent depths.

Immediately upon complete thawing the temperature of the sand and gravel rose at once a few degrees above that of the clay and loam and several degrees above that of peat. In about three or four days, however, from the day that the actual thawing occurred, March 31, and freezing did not reoccur, the temperature of the sand, gravel, loam and clay reached about the same degree; that of peat, however, did not rise to the same magnitude until April 26 or about 27 days later. The reason for this is that its 12-inch depth did not begin to thaw until April 15 or almost one month after the corresponding depth of the other soils commenced to thaw. As soon as its entire frozen layer, however, had thawed then its temperature rose rapidly and approached that of the other soils in a short time.

The slow rate of thawing of peat and the rapid ascend of its temperature thereafter is extremely interesting and suggests very strongly that it is the latent heat of fusion of ice, which amounts to 80 calories per gram of water, which delays the warming of those soils possessing a large amount of water and not necessarily the high specific heat of the water in the liquid state. This inference finds strong confirmation in the fact that during the fall the peat which possesses the greatest total specific heat cools at the same rate and has practically identical temperature as the other soils.

The rapidity with which the clay and loam thawed and the rise of their temperature to the same magnitude as that of the sand and gravel in such a short time contradicts the exaggerated general belief that these soils possess a greatly lower temperature during the spring and therefore should be classed as cold soils.

Although by April 26 the average temperature of all the different types of soil approached the same magnitude it did not come any nearer between them, as it continued to rise in the subsequent months, until next September. Thus during the months of May, June, July and August it varied appreciably in the different types, being always highest in sand and gravel followed by loam, clay and peat, respectively. At some days the sand and gravel had as much as 10°F higher temperature than the peat at the 6-inch depth. This large difference, however, occurred only whenever the air temperature rose very high suddenly. As a monthly

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average during May and June the sand and gravel were about 4 or 5° F warmer than the peat at the 6-inch depth and only about 2°F warmer than the clay and loam, while as an average during the months of July and August the sand and gravel had only about 2 or 3°F higher temperature than peat and about 1 or 2°F greater than the clay and loam.

The higher average temperature of the sand and gravel over that of the clay, loam and peat during the spring and summer months, when their surface was not covered by a thin layer of sand as in the first year, is very noteworthy. It goes to show that those soils which possess a high moisture content are kept somewhat colder, during those months that the temperature rises, than the soils of low water-holding capacity, in spite of the darker color of some of the former. Evidently, these various soils lose different amounts of water through evaporation and consequently maintain different degrees of temperature.

That the factor of evaporation is the casual agent for this variation in temperature between the different classes of soil is shown by the fact that when the surface of these soils is covered by a thin layer of sand so that the evaporation of their water is more or less equalized, this variation disappears, and all the soils have practically equal magnitude of temperature as will be subsequently shown.

The highest daily average temperature for the year was reached between June 28 and 29 by all soils and at all three depths. The magnitude of temperature on June 28 for the 6, 12 and 18-in. depths respectively was as follows: gravel 87.83°, 81.30°, 78.70°; sand 85.03°, 79.87°, 75.67°; loam 85.83°, 79.00°, 73.37°; clay 84.40°, 78.33°, 73.87°; and, peat 80.37°, 74.73°, 70.97°F.

The highest monthly average temperature, however, occurred in July and ranged as follows for the 6, 12 and 18-inch depths, respectively: gravel 78.73°, 75.77°, 74.74°; sand 77.23°, 74.79°, 73.34°; loam 77.89°, 75.25°, 72.55°; clay 76.38°, 74.11°, 72.79°; and, peat 75.34°, 73.75°, 71.96°F.

The high temperature continued to prevail until August and then began to diminish. The differences in temperature between the various types of soil also commenced to decrease in August and by the middle of September they had almost entirely disappeared and the various soils then began to have identical degree of temperature. From this period on throughout the months of October and November or until the beginning of the third year in December, they cooled at about the same rate and maintained practically equal magnitude of temperature.

There were days, of course, when the average temperature of the different soils varied appreciably. But this occurred only whenever the air temperature changed very rapidly. On such occasions the peat would have a slightly higher temperature than the other soils if the air temperature went down rapidly, while the mineral soils and especially the sand and gravel would manifest a slightly higher temperature if the air temperature rose suddenly and rapidly. But as an average for the month all the soils were equally warm.

The same rate of cooling and equal magnitude of average temperature of the diverse classes of soil during the fall months occurred in all four years and are indeed remarkably interesting and contrary to the general popular belief. It has been popularly believed that since the sandy



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and gravelly types of soil contain a low percentage of water and consequently a small total heat capacity, they would cool at a greater rate and have a lower average temperature in the fall than such classes of soil as the loam, clay and peat which contain a relatively high water content and hence a large heat capacity.

This even rate of cooling and equal average temperature in the fall and winter months of the different types of soil both when their surface is covered with the thin layer of sand and when it remains uncovered indicate that there is no one intrinsic factor during this period which is sufficiently powerful to predominate and cause a variation in the temperature of these various soils.

The main and most important facts revealed by the daily and monthly march of the temperature of the different types of soil during the second year when they were not covered with a layer of sand may be summarized then as follows: (1) All these diverse types of soil froze at about the same time at the various corresponding depths, with peat at a slightly lower rate and had practically the same magnitude of temperature throughout the winter; (2) During a period of cold weather they all reached an equal minimum of temperature and at the same day at all three depths; (3) In the spring the sand and gravel thawed first, followed by loam and clay about one or two days later and peat several days later, down to the 18-inch depth; (4) Immediately upon complete thawing the average temperature of the sand and gravel rose a few degrees above that of the loam and clay and several of that of peat. In about three or four days, however, the temperature of the clay and loam rose to about the same magnitude as that of the sand and gravel, but that of the peat required considerably longer time to approach the same point; (5)The temperature of all the soils at all three depths continued to rise, after complete thawing, and almost attained the same magnitude but it did not become equal until in the fall. Up to this time it varied, being highest in the sand and gravel, followed in order by loam, clay and peat, respectively; (6) With the commencement of the fall the temperature of all the soils began to be equal and continued to be about the same throughout the fall months until the third year began in December.

It will now be seen how the foregoing results compare with those of the following or third year.

With the commencement of the third year, December 1, 1913 to November 30, 1914, all the different types of soil were again covered with a thin layer of sand as in the first year, December 1, 1911 to November 30, 1912. The daily and monthly average temperature of the third year are contained in Tables 13 to 24 inclusive.

An examination of these tables reveals (1) that all the different types of soil at all three depths did not freeze during the winter of the third year. Toward the last week of December the 6-inch depth of the various soils approached the freezing point but their temperature rose to about 33°F and prevailed at this point throughout the winter until in the spring when it began to rise. The temperature of the 12-inch depth remained throughout the entire winter at about 35°F and that of the 18-inch depth at about 36°F. The magnitude of the daily and monthly average temperature was remarkably close in all types at the respective depths.

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(2) Signs of rise of temperature began to be manifested by March 14 but the real ascent did not commence until March 25. The temperature of the sand, gravel, loam and clay at the 6-inch depth rose almost simultaneously to about 40°F; that of the peat at the corresponding depth did not reach this point until March 31 or 6 days later. From this date on the average temperature of all the various soils tended to be equal. During the month of April it varied only about 1 or 2°F as a monthly average but as high as 7 or 8°F on certain individual days when the air temperature underwent rapid changes. During the months of May, June, July, August, September, October, and November, indeed up to the next cycle, the average temperature of all these distinct classes of soil was almost exactly the same. As a monthly average, the highest variation that occurred between any of them was only a little over 1°F. The peat especially at the 6-inch depth had a slightly higher temperature during the warmest part of the year than the other soils. The daily highest average temperature was attained on June 10. The magnitude on this date was as follows for the 6, 12 and 18-inch depths, respectively: gravel 81.90°, 76.50°, 73.93°; sand 81.47°, 75.00°, 70.97°; loam 80.93°, 74.23°, 67.97°; clay 80.47°, 73.77°, 70.07°; and, peat 81.03°, 72.27°, 67.20F. The monthly highest average temperature, however was reached in July with the following magnitudes: gravel 75.92°, 74.08°, 72.62°; sand 75.24°, 73.30°, 71.53°; loam 75.80°, 73.27°, 70.15°; clay 75.31°, 72.27°, 71.26°; and, peat 76.93°, 74.06°, 71.74°F for the 6, 12, and 18-inch depths, respectively.

The results of the spring and summer months of the third year, therefore agree almost perfectly with those of the first year, but disagree with those of the second year. As already seen in the second year the average temperature of the different soils varied appreciably during the spring and summer months, with the sand and gravel having the highest temperature followed by loam, clay and peat, respectively.

During the first and third year, however, all the diverse classes of soil were covered with a thin layer of sand, as already stated, while during the second year this cover of sand was not present and consequently the natural surface of these soils was exposed to the atmosphere.

The remarkable equality of temperature, therfore, of the various types of soil during the first and third year when their surface was covered with a thin layer of sand and its inequality during the second year when their surface was not covered suggest the noteworthy fact that it is the thin layer of sand that caused the equality. It accomplished this mainly by equalizing to a greater or less extent the amount of water that the various soils lost through evaporation. The clay, loam, and peat and especially the latter, for instance, possessing a high water content tended to lose more water through evaporation than the sand and gravel whose water content is low, and consequently their temperature was kept lower, just as the results of the second year show. By placing a thin layer of sand, which acted as a mulch, over these types of soil whose water content is high, the evaporation of their moisture was reduced, and their temperature was thereby raised to the same magnitude as that of the soils with a low water content. It was the inequality in the amount of evaporation, therefore, that caused the various types of soil to have different degrees of temperature; and when this difference in

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evaporation was prevented, then all the diverse classes of soil were equally warm during the spring and summer months.

The knowledge, therefore, that a thin layer of sand at the surface is capable of raising several degrees the temperature of clay and loam and especially of peat, is of the greatest practical importance.

It has already been stated that up to the end of the third year the temperature of the different types of soil was measured at 6, 12, and 18-inch depths. With the beginning of the fourth year, December 1, 1914 to November 30, 1915, the thermometers were removed and placed at the depths of 2, 4, and 6 inches. This change was made with the desire to obtain information on the soil temperature more close to the surface, and also to ascertain whether the general trend of order of the magnitude of temperature at the upper depths would be similar to that at the lower depths. The cover of sand was also removed from the top of these soils so that their natural surface was exposed to the atmosphere during this year. The data obtained during the fourth year are contained in Tables 25 to 36 inclusive.

An examination of these tables shows that (1) all the different types of soil began to freeze almost simultaneously at the respective depths with peat at a slightly slower rate. By the end of December they had all frozen practically down to the 6-inch depth. From this period on they remained at the freezing point throughout the winter until in the spring when they commenced to thaw. During the winter months their temperature was not only almost exactly the same at any corresponding depth but also of practically equal magnitude at all depths. In other words the upper 6-inch layer of soil had the same magnitude of temperature. The lowest average temperature was reached on January 30. At this date the average temperature of the sand went down a few degrees lower than that of the other soils.

(2) Thawing began to occur by March 12 but it did not actually commence until April 1. The gravel, sand, loam, and clay thawed almost simultaneously, with peat about four days later. The temperature of the mineral soils rose quite rapidly to about the same degree, followed by peat with a few days later.

(3) The average temperature of all the soils then tended to be equal, as it ascended, but it did not reach equality until about September. Up to this time the magnitude varied in the different types, being greatest in sand and gravel, followed by clay, loam, and peat, respectively. The temperature of peat, however, was only about 2°F lower than that of the sand or gravel at any corresponding depth, throughout the months of May, June, July, and August.

(4) By the beginning of September this variation in average temperature in the different soils began to disappear and the magnitude became practically identical in all of them at all three depths, and continued to be equal until November 30, which is the end of the year.

The results of the fourth year, show, therefore, that the average temperature of the upper depths of the various types of soil behaved almost in the same manner as that of the lower depths of the second year or corresponding year, when the surface of the soils was not covered with the sand.

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### THE DAILY REVERSION OF TEMPERATURE AND THE TEMPERATURE GRADIENT AT THE ADJACENT DEPTHS.

Unless the soil is frozen it almost always has a gradient of temperature at its adjacent depths. This gradient of temperature, however reverses itself between day and night during the warm part of the year to the depth that the diurnal-nocturnal amplitude of oscillation of temperature extends. During the day it decreases from the surface downward and during the night the reverse is true. There are periods, however, both in the night and day, when this gradient is not regular. This occurs usually at the time that the reversion takes place. The magnitude of the gradient between the different depths varies with the time, both at day and night, and the air temperaure.

This gradient of soil temperature at the adjacent depths and its reversion between day and night is due, of course, to the fact that the air temperature reverses itself during these periods and the soil receives or loses its heat more at the surface, at any given time, than at the increasing depths.

The soil, down to the depth that the diurnal-nocturnal amplitude of oscillation of temperature extends, receives its temperature in the form of waves. Thus, for instance, in the morning before sunrise, there occurs at its surface a minimum temperature. At this time the temperature is lowest at the surface and increases with depth. As soon as the air temperature begins to rise, however, the temperature at the surface of the soil also commences to climb. The minimum temperature, however, is travelling downward as a wave, and lowers the temperature of the various depths as it reaches them. But as soon as the temperature begins to rise at the surface, it also is conducted downward as a wave and immediately follows the minimum temperature wave, and causes a rise in temperature. At about this point a reversion takes place at and near the surface and the gradient becomes discontinuous. The soil then at the upper and lower depths has a higher temperature than at the intermediate.

The intensity of the minimum wave becomes less and less as it travels downward until finally it reaches a depth where its influence is no longer perceptible. The warm wave, which immediately follows it causes then the temperature of all the depths to rise. A gradient then is again established and decreases in magnitude from the surface downward. The magnitude of this gradient between the adjacent depths increases, as the temperature rises in all depths, until the maximum temperature is attained at the surface when it becomes greatest. At this time the surface soil possesses a very high temperature and the temperature falls very rapidly with the increase in depth.

The maximum temperature which occurred at the surface travels to the lower depths as a maximum wave, and imparts to the different depths a maximum temperature at different times.

But this maximum wave is immediately followed by a cold wave which lowers the temperature at the various depths and decreases the magnitude of the gradient. The cold waves of different intensities continue to travel through the soil, and to cause a reversion of its temperature in the same manner as the warm waves already discussed.

A concrete illustration of the propogation of these cold and warm

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waves into the soil and the degree of temperature gradient at the adjacent depths at any particular time, are afforded by tables 37 and 38, which contain the temperature of the different types of soil at four different depths taken every 20 minutes from the time that the minimum or maximum temperature occurred at the surface to the time they had reached the lowest depth in all the soils. These records are a few of a great number that were taken at various times throughout the four years. The data presented here were obtaind during the fourth year when the thermometers were placed at 2, 4, and 6 inches from the top. The temperature at 0 inch depth or at the surface was taken by a mercury thermometer which had a very small bulb. This bulb was inserted into the surface soil until it was completely covered. It registered the temperature only of the upper ¼-inch depth.

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TABLE 37.—THE DAILY REVERSION OF TEMPERATURE AND THE TEMPERATURE GRADIENT AT THE ADJACENT DEPTHS.

| October 22, 1915. | | P. M. 12:40 | 1:00 | 1:20 | 1:40 | 2:00 | 2:20 | 2:40 | 3:00 | 3:20 | 3:40 | 4:00 | 4:20 | 4:40 | 5:00 | 5:20 | 5:40 | 6:00 | 6:20 | 6:40 | 7:00 | 7:20 | 7:40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 0″ | 70.0 | 69.7 | 69.0 | 68.3 | 67.7 | 66.9 | 65.4 | 64.1 | 62.0 | 60.8 | 58.5 | 56.0 | 54 0 | 52.6 | 51.2 | 50.4 | 49.8 | 49.2 | 48.5 | 48.0 | 47.6 | 47.0 |
| | 2″ | 62.2 | 62.5 | 62.8 | 63.0 | 62.9 | 62.8 | 62.5 | 62.0 | 61.5 | 60.8 | 59.9 | 58.8 | 57.7 | 56.6 | 55.4 | 54.5 | 53.7 | 53.1 | 52.5 | 51.9 | 51.3 | 50.8 |
| | 4″ | 57.6 | 58.1 | 58.5 | 59.0 | 59.3 | 59.5 | 59.7 | 59.8 | 59.6 | 59.3 | 58.9 | 58.5 | 57.9 | 57.4 | 56.6 | 55.9 | 55.3 | 54.6 | 54.1 | 53.7 | 53 2 | 52.9 |
| | 6″ | 53.7 | 54.1 | 54.8 | 55.3 | 55.7 | 56.1 | 56.5 | 56.8 | 57.0 | 57.0 | 57.1 | 57.1 | 57.0 | 56.8 | 56.5 | 56.2 | 55.7 | 55.3 | 55.1 | 54.8 | 54.3 | 54.0 |
| Sand | 0″ | 69.6 | 69.0 | 68.8 | 68.0 | 67.1 | 66.2 | 65.0 | 63.8 | 61.8 | 60.5 | 58.3 | 55.9 | 53.9 | 52.2 | 51.0 | 50.0 | 49.3 | 48.6 | 47.9 | 47.4 | 46.6 | 45.8 |
| | 2″ | 63.4 | 63.8 | 64.2 | 64.3 | 64.2 | 64.1 | 63.8 | 63.3 | 62.6 | 62.0 | 60.9 | 59.7 | 58.4 | 57.2 | 56.0 | 54.8 | 53.9 | 53.3 | 52.6 | 51.8 | 51.3 | 50.7 |
| | 4″ | 59.5 | 60.1 | 60.8 | 61.3 | 61.5 | 61.7 | 61.7 | 61.7 | 61.4 | 60.9 | 60.5 | 59.8 | 58.9 | 58.1 | 57.2 | 56.4 | 55.5 | 54.8 | 54.2 | 53.7 | 53.0 | 52.5 |
| | 6″ | 55.0 | 55.7 | 56.5 | 57.0 | 57.5 | 58.0 | 58.4 | 58.5 | 58.7 | 58.9 | 58.8 | 58.5 | 58.3 | 57.0 | 57.6 | 57.1 | 56.8 | 56.3 | 55.8 | 55.3 | 54.8 | 54.3 |
| Loam | 0″ | 69.7 | 69.3 | 68.9 | 68.0 | 67.4 | 66.4 | 65.0 | 63.5 | 61.7 | 60.0 | 57.4 | 55.0 | 53.0 | 51.7 | 50.3 | 49.7 | 49.0 | 48.4 | 47.6 | 47.2 | 46.6 | 46.0 |
| | 2″ | 59.0 | 59.6 | 60.0 | 60.5 | 60.7 | 60.8 | 60.8 | 60.6 | 60.0 | 59.8 | 59.1 | 58.4 | 57.5 | 56.6 | 55.7 | 54.9 | 54.1 | 53.5 | 53.0 | 52.5 | 51.9 | 51.5 |
| | 4″ | 53.3 | 53.9 | 54.5 | 55.0 | 55.5 | 56.0 | 56.4 | 56.6 | 56.8 | 56.8 | 56 8 | 56.8 | 56.7 | 56.4 | 56.0 | 55.7 | 55.3 | 55.0 | 54.6 | 54.3 | 53.9 | 53.6 |
| | 6″ | 50.1 | 50.5 | 50.8 | 51.2 | 51.6 | 52.0 | 52.4 | 52.8 | 53.0 | 53.1 | 53.4 | 53.6 | 53.7 | 53.9 | 53.9 | 53.8 | 53.8 | 53.7 | 53.6 | 53.5 | 53.4 | 53.3 |
| Clay | 0″ | 66.0 | 65.9 | 65.7 | 65.0 | 64.4 | 63.6 | 62.4 | 61.2 | 59.7 | 58.2 | 56.3 | 54.0 | 52.0 | 50.9 | 49.7 | 48.9 | 48.5 | 47.9 | 47.0 | 46.7 | 46.1 | 45.6 |
| | 2″ | 57.5 | 58.0 | 58.5 | 58.8 | 59.0 | 59.0 | 59.0 | 58.7 | 58.4 | 58.1 | 57.5 | 57.0 | 56.1 | 55.3 | 54.4 | 53.8 | 53.2 | 52.7 | 52.1 | 51.7 | 51.2 | 50.8 |
| | 4″ | 52.9 | 53.4 | 53.9 | 54.3 | 54.8 | 55.2 | 55.4 | 55.7 | 55.8 | 55.8 | 55.8 | 55.7 | 55.5 | 55.2 | 54.9 | 54.5 | 54.0 | 53.8 | 53.5 | 53.2 | 53.0 | 52.6 |
| | 6″ | 50.6 | 51.0 | 51.4 | 51.8 | 52.1 | 52.5 | 52.9 | 53.0 | 53.4 | 53.6 | 53.7 | 53.9 | 53.9 | 54.0 | 53.9 | 53.9 | 53.9 | 53.7 | 53.7 | 53.5 | 53.4 | 53.2 |
| Peat | 0″ | 67.8 | 67.7 | 66.7 | 65.3 | 64.9 | 64.0 | 62.8 | 61.6 | 60.0 | 58.4 | 56.0 | 53.4 | 51.3 | 49.4 | 48.0 | 47.0 | 46.8 | 46.0 | 45.3 | 45.0 | 44.8 | 43.9 |
| | 2″ | 55.4 | 56.1 | 56.9 | 57.2 | 57.5 | 57.8 | 57.8 | 57.8 | 57.6 | 57.4 | 57.0 | 56.5 | 55.8 | 55.0 | 54.4 | 53.7 | 53.0 | 52.5 | 52.0 | 51.5 | 51.0 | 50.6 |
| | 4″ | 49.0 | 49.6 | 50.0 | 50.6 | 51.0 | 51.4 | 51.8 | 52.1 | 52.6 | 52.7 | 52.9 | 53.1 | 53.2 | 53.2 | 53.2 | 53.2 | 53 2 | 53.0 | 52.9 | 52.8 | 52.6 | 52.4 |
| | 6″ | 49.7 | 49.9 | 50.0 | 50.1 | 50.3 | 50.5 | 50.6 | 50.8 | 51.0 | 51.1 | 51.3 | 51.5 | 51.6 | 51.8 | 51.9 | 52.1 | 52.1 | 52.3 | 52.4 | 52.5 | 52.5 | 52.5 |

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TABLE 37.—*Continued.*

| October 23, 1915. | | A. M. 5:20 | 5:40 | 6:00 | 6:20 | 6:40 | 7:00 | 7:20 | 7:40 | 8:00 | 8:20 | 8:40 | 9:00 | 9:20 | 9:40 | 10:00 | 10:20 | 10:40 | 11:00 | 11:20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 0" | 38.4 | 38.3 | 38.0 | 38.1 | 39.0 | 40.6 | 42.5 | 44.2 | 46.0 | 47.2 | 48.8 | 51.0 | 50.7 | 51.9 | 53.7 | 55.4 | 59.0 | 61.5 | 62.9 |
| | 2" | 43.1 | 42.8 | 42.5 | 42.3 | 42.3 | 42.3 | 42.8 | 43.5 | 44.3 | 45.1 | 45.7 | 46.7 | 47.5 | 48.3 | 49.1 | 50 0 | 51.1 | 52.7 | 54.2 |
| | 4" | 45.4 | 45.2 | 45.1 | 45.0 | 44.8 | 44.7 | 44.6 | 44.8 | 45.1 | 45.4 | 45.8 | 46.2 | 46.9 | 47.4 | 47.9 | 48.3 | 49.3 | 49.9 | 51.0 |
| | 6" | 48.5 | 48.4 | 48.3 | 48.2 | 47.7 | 47.1 | 46.9 | 46.7 | 46.6 | 46.7 | 46.9 | 47.0 | 47.2 | 47.5 | 47.7 | 47.9 | 48.3 | 48.7 | 49.2 |
| Sand | 0" | 37.0 | 36.8 | 36.3 | 36.5 | 36.9 | 38.8 | 41.0 | 43.0 | 45.0 | 46.2 | 47.9 | 50.0 | 49.8 | 50.8 | 52.4 | 54.3 | 57.6 | 60.2 | 61.7 |
| | 2" | 41.5 | 41.2 | 40.9 | 40.7 | 40.5 | 40.6 | 41.0 | 41.9 | 42.9 | 43.9 | 44 8 | 45.8 | 46.9 | 47.8 | 48.4 | 49.6 | 50.8 | 52.6 | 54.3 |
| | 4" | 43.9 | 43.7 | 43.3 | 43.1 | 42.9 | 42.7 | 42.7 | 43.0 | 43.3 | 44.2 | 44.7 | 45.3 | 46.1 | 46.7 | 47.4 | 48.0 | 49.1 | 50.0 | 51.3 |
| | 6" | 46.8 | 46.4 | 46.3 | 46.0 | 45.6 | 45.5 | 45.4 | 45.3 | 45.3 | 45.4 | 45.5 | 45.9 | 46.3 | 46.6 | 46.9 | 47.4 | 48.3 | 48.4 | 49.3 |
| Loam | 0" | 37.8 | 37.6 | 37.2 | 37.3 | 38.0 | 39.8 | 42.6 | 44.6 | 46.0 | 47.0 | 48.4 | 50.8 | 50.0 | 51.2 | 53.6 | 55.0 | 58.7 | 60.9 | 62.6 |
| | 2" | 44.2 | 43.6 | 43.4 | 43 4 | 42.9 | 42.8 | 42.9 | 43.3 | 43.8 | 44 5 | 44.9 | 45.5 | 46.2 | 46 9 | 47.5 | 48.2 | 48.5 | 50.1 | 51.5 |
| | 4" | 47.4 | 47.2 | 47.1 | 46.8 | 46.7 | 46.5 | 46.1 | 46.1 | 46.1 | 46.1 | 46.3 | 46.4 | 46.5 | 46.9 | 47.3 | 47.4 | 47.9 | 48.2 | 48.4 |
| | 6" | 48.8 | 48.6 | 48.4 | 48.3 | 48.2 | 48.1 | 47.6 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.5 | 47.4 | 47.5 | 47.5 | 47.7 | 48.0 |
| Clay | 0" | 37.6 | 37.4 | 37.0 | 37.0 | 38.0 | 38.8 | 41.0 | 43.0 | 44.9 | 45.7 | 47.0 | 49.0 | 48.6 | 49.8 | 51.4 | 52.9 | 56.0 | 58.0 | 59.2 |
| | 2" | 44.4 | 43.8 | 43.6 | 43.4 | 43.1 | 43.0 | 43.0 | 43.5 | 43.9 | 44.4 | 45.0 | 45.4 | 46.2 | 46.8 | 47.4 | 48.0 | 48.5 | 49.6 | 51.0 |
| | 4" | 47.0 | 46.6 | 46.4 | 46.1 | 46.0 | 45.8 | 45.3 | 45.3 | 45.3 | 45.4 | 45.8 | 45.9 | 46.3 | 46.5 | 46.8 | 47.3 | 47.5 | 47.9 | 48.4 |
| | 6" | 48.7 | 48.6 | 48.5 | 48.4 | 48.4 | 48.0 | 48.0 | 47.7 | 47.5 | 47.4 | 47.4 | 47.4 | 47.4 | 47.5 | 47.5 | 47.8 | 47.9 | 47.9 | 48.4 |
| Peat | 0" | 34.3 | 34.2 | 33.0 | 33.0 | 33 6 | 35.5 | 38.6 | 41.0 | 43.9 | 45.0 | 47.0 | 49.3 | 49.6 | 50.8 | 52.9 | 54.6 | 59.0 | 61.6 | 63.8 |
| | 2" | 45.4 | 42.6 | 42.4 | 42.2 | 41.8 | 41.6 | 41.5 | 41.7 | 42.0 | 42.5 | 43.0 | 43.6 | 44.4 | 45 1 | 45.7 | 46.4 | 47.1 | 47.5 | 49.0 |
| | 4" | 47.5 | 47.2 | 47.0 | 46.9 | 46 8 | 46.5 | 46 3 | 46.2 | 45.5 | 45.5 | 45.7 | 45.7 | 45.9 | 45.8 | 45 8 | 46.0 | 46.2 | 46.5 | 46.7 |
| | 6" | 50.9 | 50.7 | 50.5 | 50.5 | 50.4 | 50.4 | 50.3 | 50.2 | 50.0 | 49.8 | 49.7 | 49 6 | 49 6 | 49 5 | 49.4 | 49.2 | 49.2 | 49.2 | 49.2 |

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TABLE 38.—THE DAILY REVERSION OF TEMPERATURE AND THE TEMPERATURE GRADIENT AT THE ADJACENT DEPTHS.

| July 9, 1915. | | P. M. 1:00 | 1:30 | 1:50 | 2:10 | 2:30 | 2:50 | 3:10 | 3:30 | 3:50 | 4:10 | 4:30 | 4:50 | 5:10 | 5:30 | 5:50 | 6:10 | 6:30 | 6:50 | 7:10 | 7:30 | 7:50 | 8:10 | 8:30 | 8:50 | 9:10 | 9:30 | 9:50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel.. | 0″ | 102.0 | 101.6 | 101.7 | 99.0 | 99.8 | 100.2 | 98.3 | 96.0 | 93.3 | 90.0 | 87.7 | 86.1 | 83.5 | 82.2 | 81.8 | 78.9 | 77.0 | 75.0 | 73.4 | 71.9 | 70.9 | 70.0 | 69.4 | 69.0 | 68.4 | 68.0 | 67.3 |
| | 2″ | 92.1 | 92.9 | 93.3 | 93.5 | 93.2 | 93.2 | 93.1 | 93.1 | 91.8 | 90.7 | 89.1 | 87.8 | 86.4 | 85.2 | 84.0 | 82.1 | 81.5 | 80.3 | 78.9 | 77.5 | 76.7 | 75.8 | 74.9 | 74.0 | 73.4 | 72.6 | 72.0 |
| | 4″ | 83.9 | 84.7 | 85.4 | 86.0 | 86.4 | 86.6 | 86.9 | 87.0 | 86.9 | 86.4 | 86.0 | 85.3 | 84.5 | 83.9 | 83.0 | 82.3 | 81.3 | 80.4 | 79.5 | 78.4 | 77.8 | 77.0 | 76.3 | 75.5 | 74.8 | 74.1 | 73.6 |
| | 6″ | 76.1 | 77.0 | 77.7 | 78.3 | 79.1 | 79.6 | 80.1 | 80.5 | 80.8 | 81.0 | 81.1 | 81.0 | 80.9 | 80.6 | 80.4 | 80.2 | 79.6 | 79.1 | 78.7 | 77.9 | 77.6 | 77.0 | 76.5 | 76.0 | 75.5 | 74.9 | 74.5 |
| Sand.... | 0″ | 105.0 | 104.4 | 104.0 | 101.4 | 101.1 | 101.3 | 99.9 | 97.6 | 94.7 | 91.2 | 88.9 | 87.2 | 84.6 | 83.4 | 81.9 | 79.6 | 77.4 | 75.4 | 73.7 | 71.9 | 70.8 | 70.0 | 69.0 | 68.6 | 68.0 | 67.4 | 66.7 |
| | 2″ | 94.5 | 94.8 | 95.2 | 95.4 | 94.9 | 94.8 | 94.7 | 94.3 | 93.3 | 92.1 | 90.8 | 89.4 | 87.5 | 86.7 | 85.5 | 84.2 | 83.8 | 81.5 | 80.2 | 78.6 | 77.8 | 76.8 | 75.8 | 74.8 | 74.1 | 73.4 | 72.6 |
| | 4″ | 88.1 | 88.8 | 89.3 | 89.9 | 90.1 | 90.1 | 90.2 | 90.3 | 89.8 | 89.4 | 88.6 | 87.7 | 86.4 | 85.8 | 84.9 | 83.9 | 82.9 | 82.0 | 80.8 | 79.6 | 78.9 | 78.0 | 77.2 | 76.4 | 75.5 | 74.9 | 74.1 |
| | 6″ | 80.5 | 81.3 | 82.1 | 82.8 | 83.4 | 83.9 | 84.3 | 84.5 | 84.8 | 85.0 | 84.8 | 84.6 | 84.1 | 83.8 | 83.4 | 82.8 | 82.2 | 81.6 | 80.8 | 80.2 | 79.6 | 78.9 | 78.2 | 77.6 | 76.9 | 76.3 | 75.8 |
| Loam... | 0″ | 100.7 | 100.0 | 100.2 | 97.9 | 98.3 | 98.7 | 97.2 | 95.0 | 92.0 | 88.9 | 86.4 | 85.0 | 82.4 | 81.3 | 79.9 | 78.0 | 76.1 | 74.4 | 72.8 | 71.0 | 70.1 | 69.8 | 68.8 | 68.3 | 67.8 | 67.2 | 66.8 |
| | 2″ | 83.8 | 84.6 | 85.5 | 85.3 | 86.0 | 86.1 | 85.5 | 85.9 | 84.4 | 84.9 | 84.1 | 83.1 | 82.1 | 81.3 | 80.5 | 79.6 | 78.6 | 77.8 | 76.6 | 75.4 | 74.7 | 73.9 | 73.1 | 72.3 | 71.7 | 71.1 | 70.5 |
| | 4″ | 75.8 | 76.6 | 77.4 | 78.0 | 78.6 | 79.0 | 79.5 | 80.0 | 80.3 | 80.4 | 80.4 | 80.4 | 80.0 | 80.0 | 79.5 | 79.1 | 78.8 | 78.3 | 77.8 | 77.1 | 76.9 | 76.4 | 75.8 | 75.4 | 74.9 | 74.5 | 74.0 |
| | 6″ | 68.0 | 68.7 | 69.4 | 69.9 | 70.5 | 71.0 | 71.4 | 71.8 | 72.4 | 72.9 | 73.2 | 73.5 | 73.7 | 73.9 | 73.9 | 74.0 | 74.1 | 74.0 | 73.8 | 73.7 | 73.6 | 73.5 | 73.2 | 73.0 | 72.8 | 72.4 | 72.2 |
| Clay.... | 0″ | 97.2 | 96.9 | 97.0 | 94.9 | 95.0 | 95.0 | 93.6 | 91.4 | 88.9 | 85.9 | 83.9 | 82.4 | 80.0 | 79.0 | 78.2 | 76.0 | 74.4 | 72.9 | 71.2 | 69.9 | 69.3 | 68.3 | 67.7 | 67.2 | 67.0 | 66.5 | 66.0 |
| | 2″ | 82.9 | 83.6 | 84.1 | 84.5 | 84.5 | 84.5 | 84.6 | 84.5 | 84.1 | 83.5 | 82.8 | 81.9 | 80.8 | 80.4 | 79.5 | 78.7 | 77.9 | 77.0 | 76.1 | 74.8 | 74.5 | 73.8 | 73.0 | 72.3 | 71.7 | 71.3 | 70.8 |
| | 4″ | 73.3 | 73.8 | 74.5 | 75.3 | 75.8 | 75.9 | 76.0 | 76.1 | 76.3 | 76.6 | 76.9 | 76.8 | 76 6 | 76.3 | 75.8 | 75.5 | 74.9 | 74.6 | 74.0 | 73.7 | 73.4 | 72.9 | 72.2 | 71.6 | 71.4 | 70.9 | 70.5 |
| | 6″ | 68.8 | 69.4 | 70.0 | 70.5 | 71.1 | 71.7 | 72.0 | 72.5 | 72.9 | 73.4 | 73.6 | 73.9 | 73.9 | 74.1 | 74.0 | 74.0 | 73.9 | 73.8 | 73.6 | 73.4 | 73.3 | 73.1 | 72.8 | 72.5 | 72.3 | 72.0 | 71.8 |
| Peat.... | 0″ | 97.9 | 97.4 | 97.3 | 95.0 | 95.4 | 94.9 | 92.9 | 90.9 | 88.1 | 85.2 | 83.1 | 82.0 | 79.5 | 78.4 | 76.9 | 75.2 | 73.2 | 71.4 | 69.6 | 67.8 | 66.9 | 66.0 | 65.3 | 65.3 | 64.9 | 64.5 | 63.9 |
| | 2″ | 81.4 | 82.1 | 83.0 | 83.5 | 83.8 | 84.0 | 84.2 | 84.3 | 84.0 | 83.5 | 82.9 | 82.1 | 81.1 | 80.5 | 79.9 | 79.0 | 78.2 | 77.4 | 76.4 | 75.4 | 74.7 | 74.1 | 73.3 | 72.5 | 71.8 | 71.3 | 70.8 |
| | 4″ | 69.4 | 70.0 | 70.8 | 71.2 | 71.9 | 72.5 | 73.0 | 73.6 | 73.9 | 74.2 | 74.5 | 74.7 | 74.8 | 74.8 | 74.9 | 74.7 | 74.6 | 74.5 | 74.1 | 73.9 | 73.7 | 73.5 | 73.1 | 72.8 | 72.4 | 72.0 | 71.8 |
| | 6″ | 64.8 | 65.0 | 65.4 | 66.8 | 66.2 | 66.4 | 66.7 | 67.0 | 67.3 | 67.8 | 68.1 | 68.4 | 68.7 | 68.9 | 69.1 | 69.3 | 69.6 | 69.8 | 69.9 | 70.0 | 70.0 | 70.0 | 70.1 | 70.1 | 70.1 | 70.1 | 70.0 |

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TABLE 38.—*Continued.*

| July 10, 1915. | | A. M. 3:20 | 3:40 | 4:00 | 4:20 | 4:40 | 5:00 | 5:20 | 5:40 | 6:00 | 6:20 | 6:40 | 7:00 | 7:20 | 7:40 | 8:00 | 8:20 | 8:40 | 9:00 | 9:20 | 9:40 | 10:00 | 10:20 | 10:40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gravel | 0″ | 59.0 | 59.1 | 59.0 | 59.0 | 59.7 | 60.0 | 61.6 | 63.8 | 66.5 | 68.8 | 71.7 | 73.8 | 76.3 | 78.4 | 80.3 | 82.8 | 84.8 | 86.0 | 87.4 | 89.4 | 92.9 | 95.0 | 95.4 |
| | 2″ | 64.3 | 64.0 | 63.6 | 63.4 | 63.2 | 63.1 | 63.1 | 63.5 | 64.1 | 65.1 | 66.4 | 67.8 | 69.4 | 70.8 | 72.4 | 74.0 | 75.6 | 77.6 | 79.1 | 80.9 | 82.8 | 84.5 | 86.1 |
| | 4″ | 66.7 | 66.2 | 65.8 | 65.5 | 65.3 | 65.0 | 64.9 | 64.9 | 64.9 | 65.1 | 65.7 | 66.3 | 67.0 | 68.0 | 68.9 | 69.9 | 71.1 | 72.4 | 73.7 | 74.9 | 76.4 | 77.7 | 79.0 |
| | 6″ | 68.5 | 68.2 | 67.9 | 67.5 | 67.2 | 67.0 | 66.7 | 66.5 | 66.4 | 66.3 | 66.2 | 66.4 | 66.6 | 66.9 | 67.4 | 67.8 | 68.5 | 69.2 | 69.9 | 70.6 | 71.4 | 72.4 | 73.4 |
| Sand | 0″ | 58.0 | 58.0 | 57.9 | 57.9 | 58.5 | 59.0 | 60.5 | 62.6 | 65.2 | 67.8 | 70.9 | 73.9 | 76.8 | 79.5 | 81.6 | 85.0 | 87.6 | 90.4 | 92.9 | 94.0 | 96.9 | 99.0 | 99.0 |
| | 2″ | 64.1 | 63.6 | 63.2 | 63.0 | 62.7 | 62.6 | 62.6 | 63.0 | 63.8 | 64.8 | 66.2 | 67.7 | 69.5 | 71.0 | 72.9 | 74.9 | 76.7 | 78.8 | 80.4 | 82.1 | 83.8 | 85.4 | 87.0 |
| | 4″ | 66.0 | 65.6 | 65.1 | 64.7 | 64.4 | 64.2 | 64.1 | 64.1 | 64.3 | 64.7 | 65.4 | 66.2 | 67.3 | 68.4 | 69.6 | 71.0 | 72.5 | 74.0 | 75.4 | 76.9 | 78.3 | 79.9 | 81.1 |
| | 6″ | 68.5 | 68.1 | 67.6 | 67.2 | 66.9 | 66.7 | 66.4 | 66.1 | 66.0 | 66.0 | 66.1 | 66.3 | 66.7 | 67.1 | 67.7 | 68.6 | 69.3 | 70.3 | 71.1 | 72.0 | 73.3 | 74.2 | 75.3 |
| Loam | 0″ | 58.9 | 58.9 | 58.9 | 58.9 | 59.6 | 59.9 | 60.8 | 63.1 | 66.0 | 68.0 | 70.6 | 72.9 | 75.6 | 78.0 | 80.0 | 83.0 | 85.1 | 87.7 | 89.8 | 90.4 | 93.2 | 95.0 | 95.0 |
| | 2″ | 63.6 | 63.1 | 62.9 | 62.5 | 62.3 | 62.1 | 62.0 | 62.1 | 62.3 | 62.8 | 63.4 | 64.2 | 65.3 | 66.2 | 67.4 | 69.0 | 70.5 | 72.0 | 73.6 | 74.8 | 76.2 | 77.8 | 79.2 |
| | 4″ | 68.3 | 68.0 | 67.6 | 67.2 | 67.0 | 66.8 | 66.6 | 66.4 | 66.2 | 66.0 | 66.1 | 66.2 | 66.4 | 66.7 | 67.0 | 67.6 | 68.1 | 68.8 | 69.6 | 70.1 | 71.1 | 71.7 | 72.8 |
| | 6″ | 68.5 | 68.2 | 68.0 | 67.6 | 67.5 | 67.3 | 67.0 | 66.8 | 66.5 | 66.5 | 66.3 | 66.1 | 66.1 | 66.0 | 66.1 | 66.1 | 66.3 | 66.4 | 66.7 | 66.9 | 67.2 | 67.5 | 68.0 |
| Clay | 0″ | 58.2 | 58.3 | 58.3 | 58.3 | 59.0 | 59.3 | 60.4 | 62.0 | 64.6 | 66.4 | 68.8 | 71.0 | 73.0 | 75.3 | 77.3 | 80.0 | 82.2 | 85.0 | 87.0 | 88.3 | 90.8 | 92.6 | 92.7 |
| | 2″ | 64.6 | 64.1 | 63.9 | 63.7 | 63.5 | 63.3 | 63.3 | 63.3 | 63.5 | 64.0 | 64.6 | 65.4 | 66.2 | 67.0 | 68.0 | 69.2 | 70.3 | 71.6 | 72.9 | 74.1 | 75.5 | 76.9 | 78.2 |
| | 4″ | 66.5 | 66.3 | 66.0 | 65.7 | 65.3 | 65.2 | 65.0 | 64.9 | 64.8 | 64.8 | 65.0 | 65.1 | 65.4 | 65.6 | 66.0 | 66.6 | 66.9 | 67.7 | 68.0 | 68.8 | 69.6 | 70.6 | 71.3 |
| | 6″ | 68.0 | 67.7 | 67.5 | 67.3 | 67.1 | 66.8 | 66.7 | 66.6 | 66.3 | 66.1 | 66.0 | 66.0 | 66.0 | 66.0 | 66.0 | 66.0 | 66.3 | 66.5 | 66.8 | 67.0 | 67.4 | 67.9 | 68.4 |
| Peat | 0″ | 55.3 | 55.8 | 55.5 | 55.8 | 56.9 | 57.7 | 59.9 | 62.4 | 65.7 | 68.2 | 71.0 | 73.6 | 75.8 | 77.3 | 78.4 | 80.9 | 83.0 | 85.6 | 87.8 | 89.0 | 91.3 | 93.2 | 93.3 |
| | 2″ | 64.2 | 63.8 | 63.6 | 63.1 | 62.9 | 62.7 | 62.6 | 62.6 | 63.0 | 63.3 | 64.0 | 64.7 | 65.6 | 66.5 | 67.4 | 68.6 | 69.6 | 70.9 | 72.1 | 73.5 | 74.9 | 76.4 | 77.9 |
| | 4″ | 67.4 | 67.1 | 66.9 | 66.7 | 66.5 | 66.2 | 66.0 | 65.8 | 65.6 | 65.4 | 65.3 | 65.3 | 65.3 | 65.3 | 65.4 | 65.6 | 65.8 | 66.2 | 66.5 | 66.9 | 67.4 | 67.8 | 68.4 |
| | 6″ | 68.6 | 68.4 | 68.3 | 68.1 | 68.0 | 67.9 | 67.8 | 67.6 | 67.5 | 67.3 | 67.2 | 67.0 | 67.0 | 66.9 | 66.8 | 66.8 | 66.7 | 66.7 | 66.7 | 66.7 | 66.7 | 66.8 | 66.9 |

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The above figures, therefore, show that the heat is propogated into the soil in the form already described.

They also show that the degree of gradient of temperature is much greater during the day when the maximum temperature is reached than during the night when the minimum is attained, at the surface. Thus, for instance in the former case the difference is almost as high as 30°F, while in the latter case it is only about 10°F. It is to be noted that in both instances the amplitude is greatest between the surface and 2-inch depth and decreases rapidly with the succeeding depths.

Another extremely interesting fact that is revealed by the above tables is that the rate at which the maximum and minimum waves travel at the various depths of any particular soil tends to follow approximately a mathematical law. This law may be stated as follows: the lag of the maximum and minimum epochs tends to be approximately proportional to the depth, in all the different types of soil.

The larger gradient during the day over that at night is due, of course, to the fact that during the insolation the soil receives its heat both by absorption and by contact with the warm air and since it is a poor conductor of heat the temperature rises at the top much faster than it is conducted downward. While during the night it is this high temperature at the depths that is being lost, through radiation and contact with the cold air, and since the rate of cooling is slower than that of warming, the various adjacent depths do not attain very large gradients of temperature.

The night or early morning gradient at the various adjacent depths is greatest in the fall, and slightly smaller in the summer, and spring. In the fall the magnitude between the surface and 6-inch depth is usually about 5°F while in the summer and fall it is about 3°F, in the mineral soil, and slightly higher in the peat.

The degree of gradient at the various depths both at night and day is of great importance from the standpoint of aeration and thermal movement of moisture in soils as shown by the author elsewhere[4].

[4]Technical Bul. 22. Mich. Expt. Sta., 1915.

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### EFFECT OF METEOROLOGICAL ELEMENTS ON THE SOIL TEMPERATURE.

It has already been stated that the external factors which comprise the meteorological elements act upon the intrinsic factors and cause the temperature of the soil to vary as they themselves vary. These meteorological elements, however, do not all influence the soil temperature in the same direction, and are very complex as to their behavior and consequently the influence of all of them is not readily apparent. In the previous report an attempt was made to establish a connection between the soil temperature and the various chief meteorlogical elements but it was not altogether successful. The only factors with which the soil temperature correlated very closely was the air temperature, the dew point and the sunshine during the summer.

### THE DAILY AND MONTHLY MAXIMUM AND MINIMUM TEMPERATURE AND THE MONTHLY AMPLITUDE.

Thus far the average daily march of average temperature of the various types of soil has been considered. It will now be of interest to examine the daily maximum and minimum temperature and consequently also the amplitude of these same classes of soil. The data for the three years are included in Tables 39 to 74 inclusive. As previously stated these maximum and minimum temperatures do not represent the absolute values, but they approach these actual or true values very closely.

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BEGINNING WITH SECOND YEAR.

TABLE 39.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, DECEMBER, 1912.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 Max.... | 43.7 | 42.7 | 41.9 | 44.0 | 42.6 | 42.5 | 40.9 | 40.2 | 40.6 | 42.2 | 40.6 | 40.7 | 38.6 | 37.8 | 40.7 |
| 2 Min.... | 42.0 | 41.2 | 40.3 | 41.7 | 41.3 | 40.7 | 39.1 | 38.3 | 39.8 | 40.7 | 38.8 | 39.4 | 36.4 | 37.5 | 40.6 |
| 3 Max.... | 37.7 | 39.4 | 41.5 | 37.5 | 39.6 | 41.8 | 38.3 | 40.3 | 41.4 | 38.4 | 40.6 | 41.5 | 38.2 | 38.6 | 40.9 |
| 3 Min.... | 36.8 | 38.3 | 40.7 | 36.5 | 38.3 | 41.4 | 37.0 | 39.6 | 41.3 | 37.1 | 39.6 | 41.2 | 37.3 | 38.4 | 40.8 |
| 4 Max.... | 39.0 | 39.0 | 39.9 | 38.9 | 39.1 | 40.1 | 37.5 | 38.9 | 40.9 | 38.1 | 39.0 | 40.2 | 36.5 | 38.4 | 40.7 |
| 4 Min.... | 37.1 | 38.1 | 39.6 | 36.8 | 38.1 | 39.9 | 36.8 | 38.5 | 40.0 | 37.1 | 38.5 | 39.7 | 36.4 | 38.1 | 40.6 |
| 5 Max.... | 40.4 | 39.7 | 39.9 | 40.6 | 39.7 | 40.4 | 38.1 | 38.8 | 40.5 | 38.9 | 38.9 | 39.9 | 36.7 | 38.1 | 40.5 |
| 5 Min.... | 36.4 | 37.9 | 39.7 | 35.9 | 37.9 | 39.9 | 36.4 | 38.5 | 40.3 | 36.6 | 38.5 | 39.8 | 36.3 | 37.8 | 40.3 |
| 6 Max.... | 43.2 | 42.9 | 42.3 | 43.1 | 43.1 | 42.5 | 41.9 | 41.1 | 41.4 | 42.7 | 41.2 | 41.3 | 39.7 | 39.1 | 41.0 |
| 6 Min.... | 38.2 | 39.9 | 41.7 | 38.2 | 40.0 | 41.9 | 33.9 | 40.7 | 41.1 | 39.0 | 41.0 | 41.1 | 39.1 | 38.4 | 40.9 |
| 7 Max.... | 36.1 | 38.1 | 40.8 | 36.9 | 38.2 | 41.0 | 37.1 | 39.9 | 41.5 | 37.1 | 39.8 | 41.2 | 38.0 | 39.1 | 41.2 |
| 7 Min.... | 35.1 | 37.0 | 39.7 | 35.0 | 37.2 | 40.1 | 36.1 | 39.1 | 41.0 | 36.0 | 39.0 | 40.5 | 37.2 | 38.5 | 40.4 |
| 9 Max.... | 33.1 | 35.1 | 38.2 | 34.2 | 35.6 | 38.8 | 34.2 | 37.4 | 39.7 | 34.0 | 37.2 | 38.9 | 35.5 | 38.2 | 40.9 |
| 9 Min.... | 32.9 | 34.7 | 38.0 | 33.1 | 35.0 | 38.2 | 33.9 | 37.1 | 39.5 | 33.7 | 36.6 | 38.5 | 35.0 | 37.8 | 40.6 |
| 10 Max.... | 32.5 | 34.4 | 37.2 | 32.8 | 34.8 | 37.9 | 33.6 | 36.5 | 38.9 | 33.2 | 36.3 | 38.2 | 34.7 | 37.4 | 40.3 |
| 10 Min.... | 31.7 | 33.7 | 36.9 | 32.3 | 34.1 | 37.4 | 33.1 | 36.4 | 38.7 | 32.9 | 36.1 | 37.8 | 34.4 | 37.1 | 39.3 |
| 11 Max.... | 33.0 | 34.7 | 37.5 | 33.0 | 34.9 | 37.7 | 33.4 | 36.3 | 38.5 | 33.2 | 36.1 | 37.8 | 34.3 | 37.2 | 40.1 |
| 11 Min.... | 32.1 | 33.7 | 36.6 | 32.1 | 34.3 | 37.3 | 32.9 | 35.8 | 38.1 | 32.7 | 35.5 | 37.3 | 33.6 | 36.4 | 39.3 |
| 12 Max.... | 31.1 | 33.1 | 36.4 | 31.3 | 33.8 | 37.2 | 32.7 | 35.8 | 38.0 | 32.5 | 35.5 | 37.3 | 33.7 | 36.3 | 39.1 |
| 12 Min.... | 30.2 | 32.6 | 35.7 | 30.3 | 33.0 | 36.4 | 32.2 | 35.2 | 37.6 | 31.7 | 34.9 | 36.7 | 33.0 | 36.0 | 38.6 |
| 13 Max.... | 30.2 | 32.2 | 35.7 | 30.3 | 32.9 | 36.3 | 31.7 | 35.0 | 37.5 | 31.6 | 34.8 | 36.5 | 32.9 | 35.6 | 38.7 |
| 13 Min.... | 29.7 | 31.7 | 35.0 | 29.7 | 32.2 | 35.8 | 31.3 | 34.5 | 36.9 | 31.0 | 34.1 | 36.0 | 32.4 | 35.1 | 38.2 |
| 14 Max.... | 30.9 | 31.9 | 35.3 | 30.7 | 32.7 | 35.9 | 31.3 | 34.6 | 37.0 | 31.4 | 34.2 | 36.1 | 32.7 | 35.2 | 38.2 |
| 14 Min.... | 29.0 | 31.7 | 33.9 | 28.8 | 31.2 | 34.9 | 30.3 | 33.2 | 35.9 | 30.2 | 33.0 | 34.9 | 31.4 | 34.1 | 37.5 |
| 16 Max.... | 31.0 | 32.1 | 34.8 | 31.2 | 32.9 | 35.6 | 31.3 | 33.9 | 36.2 | 31.2 | 33.8 | 35.4 | 32.3 | 34.7 | 37.3 |
| 16 Min.... | 30.9 | 31.9 | 34.7 | 31.0 | 32.8 | 35.4 | 31.2 | 33.8 | 36.2 | 31.1 | 33.6 | 35.3 | 32.0 | 34.4 | 37.2 |
| 17 Max.... | 31.4 | 32.6 | 35.0 | 32.7 | 33.4 | 35.8 | 31.6 | 34.2 | 36.4 | 31.7 | 34.0 | 35.6 | 32.4 | 34.6 | 37.3 |
| 17 Min.... | 31.1 | 32.3 | 34.7 | 31.4 | 33.0 | 35.4 | 31.2 | 33.7 | 36.2 | 31.2 | 33.6 | 35.1 | 31.9 | 34.2 | 37.1 |
| 18 Max.... | 32.4 | 33.6 | 35.8 | 33.4 | 34.6 | 36.6 | 32.2 | 34.8 | 36.8 | 32.4 | 34.6 | 36.1 | 32.8 | 34.9 | 37.7 |
| 18 Min.... | 32.3 | 33.3 | 35.7 | 33.2 | 34.3 | 36.4 | 32.0 | 34.5 | 36.6 | 32.2 | 34.4 | 35.7 | 32.8 | 34.8 | 37.5 |
| 19 Max.... | 32.9 | 34.0 | 36.0 | 33.2 | 34.8 | 36.8 | 32.3 | 34.9 | 36.9 | 32.7 | 34.9 | 36.4 | 32.9 | 34.9 | 37.7 |
| 19 Min.... | 32.4 | 33.5 | 35.7 | 33.1 | 34.6 | 36.5 | 32.2 | 34.7 | 36.6 | 32.5 | 34.8 | 36.1 | 32.8 | 34.8 | 37.4 |
| 20 Max.... | 33.1 | 34.3 | 36.0 | 33.2 | 34.7 | 36.8 | 32.5 | 35.0 | 36.9 | 32.8 | 34.9 | 36.4 | 33.0 | 34.9 | 37.6 |
| 20 Min.... | 32.7 | 33.9 | 35.8 | 32.9 | 34.2 | 36.4 | 32.1 | 34.4 | 36.5 | 32.4 | 34.5 | 35.8 | 32.7 | 34.5 | 37.2 |
| 21 Max.... | 33.0 | 34.0 | 35.9 | 33.0 | 34.6 | 36.4 | 32.4 | 34.8 | 36.6 | 32.8 | 34.9 | 36.0 | 32.9 | 34.8 | 37.4 |
| 21 Min.... | 33.0 | 34.0 | 35.8 | 32.9 | 34.4 | 36.4 | 32.3 | 34.7 | 36.4 | 32.7 | 34.8 | 35.9 | 32.8 | 34.7 | 37.2 |
| 23 Max.... | 32.7 | 33.8 | 35.8 | 32.0 | 33.7 | 36.3 | 32.0 | 34.6 | 36.1 | 32.5 | 34.7 | 35.8 | 32.4 | 34.3 | 36.9 |
| 23 Min.... | 31.4 | 32.3 | 34.9 | 31.4 | 33.1 | 35.5 | 31.4 | 33.8 | 35.7 | 31.8 | 34.0 | 35.2 | 31.9 | 33.8 | 36.4 |
| 24 Max.... | 31.5 | 32.9 | 34.9 | 31.3 | 33.0 | 35.2 | 31.2 | 33.7 | 35.8 | 31.4 | 33.7 | 35.0 | 31.6 | 33.8 | 36.3 |
| 24 Min.... | 31.3 | 32.5 | 34.5 | 31.1 | 32.7 | 35.0 | 31.0 | 33.3 | 35.4 | 31.3 | 33.4 | 35.0 | 31.4 | 33.4 | 36.0 |
| 26 Max.... | 31.9 | 33.2 | 35.2 | 31.8 | 33.1 | 35.7 | 31.6 | 34.2 | 35.9 | 31.9 | 34.1 | 35.5 | 32.2 | 34.1 | 36.6 |
| 26 Min.... | 31.6 | 32.9 | 34.9 | 31.2 | 32.8 | 35.2 | 31.2 | 33.7 | 35.7 | 31.4 | 33.7 | 35.0 | 31.9 | 33.8 | 36.4 |
| 27 Max.... | 32.6 | 33.7 | 35.5 | 32.3 | 33.8 | 35.9 | 32.1 | 34.4 | 36.3 | 32.5 | 34.4 | 35.8 | 32.7 | 34.5 | 37.0 |
| 27 Min.... | 32.2 | 33.2 | 35.1 | 31.7 | 33.2 | 35.7 | 31.8 | 34.1 | 36.0 | 32.1 | 34.2 | 35.6 | 32.1 | 34.1 | 36.8 |
| 28 Max.... | 32.2 | 33.5 | 35.5 | 31.9 | 33.4 | 35.8 | 32.0 | 34.3 | 36.2 | 32.4 | 34.3 | 35.8 | 32.5 | 34.3 | 36.9 |
| 28 Min.... | 31.0 | 32.3 | 34.6 | 31.0 | 32.7 | 34.9 | 31.1 | 33.4 | 35.1 | 31.2 | 33.6 | 35.0 | 31.7 | 33.5 | 36.2 |
| 30 Max.... | 32.1 | 33.2 | 35.1 | 32.6 | 33.2 | 35.3 | 31.7 | 33.9 | 35.7 | 32.1 | 34.1 | 35.1 | 32.0 | 33.8 | 36.3 |
| 30 Min.... | 31.6 | 32.9 | 34.9 | 31.6 | 32.9 | 35.1 | 31.2 | 33.4 | 35.3 | 31.4 | 33.6 | 35.0 | 31.7 | 33.3 | 36.2 |
| 31 Max.... | 31.9 | 33.0 | 34.8 | 31.9 | 33.2 | 35.1 | 31.4 | 33.7 | 35.6 | 31.9 | 33.8 | 35.1 | 31.9 | 33.7 | 36.3 |
| 31 Min.... | 31.7 | 32.9 | 34.7 | 31.6 | 32.9 | 35.0 | 31.2 | 33.4 | 35.2 | 31.7 | 33.4 | 34.8 | 31.4 | 33.3 | 35.9 |
| Ave. Max.. | 33.98 | 35.08 | 37.08 | 34.15 | 35.42 | 37.58 | 33.80 | 36.05 | 37.89 | 34.06 | 36.02 | 37.34 | 34.12 | 35.93 | 38.54 |
| Ave. Min.. | 32.98 | 34.34 | 36.55 | 32.98 | 34.65 | 37.07 | 33.12 | 35.51 | 37.48 | 33.27 | 35.49 | 36.90 | 33.58 | 35.51 | 38.18 |
| Ave. Range | 1.00 | 0.74 | 0.53 | 1.17 | 0.77 | 0.51 | 0.65 | 0.54 | 0.41 | 0.79 | 0.53 | 0.44 | 0.54 | 0.42 | 0.36 |

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TABLE 49.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JANUARY, 1913.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 31.7 | 32.9 | 34.3 | 31.6 | 32.9 | 34.9 | 31.2 | 33.3 | 35.0 | 31.6 | 33.6 | 34.9 | 31.6 | 33.2 | 35.9 |
| 1 Min. | 31.6 | 32.6 | 34.2 | 31.5 | 32.8 | 34.8 | 31.1 | 33.1 | 34.9 | 31.5 | 33.2 | 34.6 | 31.3 | 33.1 | 35.7 |
| 2 Max. | 31.9 | 32.9 | 34.4 | 31.8 | 33.1 | 35.2 | 31.3 | 33.6 | 35.2 | 31.9 | 33.7 | 34.9 | 31.7 | 33.4 | 35.9 |
| 2 Min. | 31.7 | 32.8 | 34.2 | 31.6 | 32.8 | 34.8 | 31.0 | 33.0 | 34.8 | 31.3 | 33.2 | 34.4 | 31.3 | 33.1 | 35.7 |
| 3 Max. | 32.7 | 33.3 | 35.0 | 32.4 | 33.7 | 35.4 | 31.7 | 33.8 | 35.5 | 32.4 | 34.1 | 35.1 | 32.0 | 33.8 | 36.2 |
| 3 Min. | 32.0 | 33.1 | 34.9 | 31.8 | 33.3 | 35.3 | 31.3 | 33.4 | 35.2 | 32.1 | 33.8 | 35.0 | 31.7 | 33.6 | 35.9 |
| 4 Max. | 32.7 | 33.4 | 35.0 | 32.4 | 33.7 | 35.4 | 31.8 | 33.9 | 35.6 | 32.3 | 34.2 | 35.2 | 32.1 | 33.8 | 36.1 |
| 4 Min. | 32.2 | 33.2 | 34.8 | 32.0 | 33.4 | 35.2 | 31.4 | 33.7 | 35.2 | 32.1 | 33.8 | 35.0 | 31.8 | 33.4 | 35.8 |
| 6 Max. | 31.7 | 32.8 | 34.7 | 31.6 | 33.0 | 34.9 | 31.3 | 33.3 | 35.2 | 31.7 | 33.6 | 35.0 | 31.7 | 33.5 | 36.0 |
| 6 Min. | 31.3 | 32.5 | 34.0 | 31.3 | 32.6 | 34.6 | 30.9 | 33.1 | 35.0 | 31.3 | 33.2 | 34.6 | 31.1 | 32.8 | 35.7 |
| 7 Max. | 32.7 | 33.6 | 35.2 | 32.6 | 33.8 | 35.6 | 31.8 | 34.2 | 35.7 | 32.5 | 34.3 | 35.6 | 32.3 | 34.2 | 36.6 |
| 7 Min. | 32.2 | 33.2 | 34.9 | 32.4 | 33.2 | 35.2 | 31.5 | 33.7 | 35.5 | 32.1 | 33.8 | 35.1 | 31.9 | 33.7 | 36.3 |
| 8 Max. | 32.7 | 33.6 | 35.1 | 32.5 | 33.8 | 35.7 | 31.8 | 34.1 | 35.8 | 32.4 | 34.2 | 35.1 | 32.2 | 34.1 | 36.5 |
| 8 Min. | 32.7 | 33.6 | 35.1 | 32.5 | 33.8 | 35.7 | 31.8 | 34.1 | 35.8 | 32.4 | 34.2 | 35.1 | 32.2 | 34.1 | 36.5 |
| 9 Max. | 31.9 | 33.2 | 34.4 | 31.7 | 33.0 | 35.0 | 31.3 | 33.4 | 35.1 | 31.8 | 33.3 | 34.8 | 31.5 | 32.8 | 35.7 |
| 9 Min. | 31.7 | 32.7 | 34.3 | 31.6 | 32.8 | 34.7 | 31.1 | 33.2 | 34.8 | 31.4 | 33.3 | 34.7 | 31.5 | 32.8 | 35.7 |
| 10 Max. | 32.2 | 33.2 | 34.8 | 32.2 | 33.1 | 35.1 | 31.7 | 33.7 | 35.3 | 32.1 | 33.6 | 34.9 | 31.9 | 33.4 | 35.9 |
| 10 Min. | 31.8 | 32.8 | 34.2 | 31.5 | 32.9 | 34.7 | 31.2 | 33.2 | 34.8 | 31.5 | 33.1 | 34.4 | 31.3 | 33.1 | 35.7 |
| 11 Max. | 32.2 | 33.1 | 34.5 | 31.9 | 33.1 | 35.0 | 31.3 | 33.3 | 35.0 | 31.9 | 33.5 | 34.7 | 31.8 | 33.4 | 35.7 |
| 11 Min. | 32.1 | 33.0 | 34.4 | 31.7 | 33.0 | 34.9 | 31.3 | 33.3 | 34.9 | 31.8 | 33.3 | 34.6 | 31.6 | 33.1 | 35.6 |
| 13 Max. | 32.7 | 33.7 | 34.9 | 32.2 | 33.7 | 35.2 | 31.9 | 33.9 | 35.2 | 32.1 | 33.9 | 35.0 | 32.0 | 33.7 | 36.1 |
| 13 Min. | 32 3 | 33.4 | 34.9 | 32.1 | 33.3 | 35.2 | 31.4 | 33.8 | 35.1 | 32.1 | 33.8 | 34.9 | 31.8 | 33.3 | 35.8 |
| 14 Max. | 33.0 | 33.8 | 35.3 | 32.4 | 33.8 | 35.6 | 31.9 | 33.9 | 35.2 | 32.3 | 34.1 | 35.2 | 32.5 | 34.0 | 36.2 |
| 14 Min. | 32.2 | 33.1 | 34.6 | 32.1 | 33.3 | 34.9 | 31.2 | 33.3 | 34.9 | 31.8 | 33.4 | 34.8 | 31.7 | 33.2 | 35.4 |
| 15 Max. | 32.8 | 33.7 | 35.1 | 32.3 | 33.6 | 35.1 | 31.7 | 33.7 | 35.2 | 32.2 | 33.9 | 34.9 | 31.8 | 33.3 | 35.8 |
| 15 Min. | 32.5 | 33.2 | 34.8 | 32.1 | 33.4 | 35.0 | 31.3 | 33.5 | 35.1 | 31.9 | 33.8 | 34.7 | 31.7 | 33.2 | 35.7 |
| 16 Max. | 32.7 | 33.6 | 34.9 | 32.2 | 33.0 | 34.3 | 31.9 | 33.8 | 35.3 | 32.2 | 33.9 | 35.0 | 31.9 | 33.7 | 36.0 |
| 16 Min. | 32.6 | 33.4 | 34.8 | 32.0 | 32.9 | 34.2 | 31.7 | 33.7 | 35.0 | 32.0 | 33.8 | 34.9 | 31.8 | 33.6 | 35.7 |
| 17 Max. | 32.4 | 33.7 | 35.0 | 32.1 | 34.0 | 34.8 | 32.0 | 33.9 | 35.1 | 32.3 | 34.0 | 34.9 | 31.9 | 33.4 | 35.8 |
| 17 Min. | 32.3 | 33.2 | 34.8 | 32 0 | 33.9 | 34.7 | 31.8 | 33.6 | 34.9 | 32.1 | 33.8 | 34.8 | 31.9 | 33.3 | 35.7 |
| 18 Max. | 32.4 | 33.9 | 35.0 | 32.3 | 33.6 | 35.1 | 31.9 | 33.8 | 35.3 | 32.2 | 34.1 | 35.1 | 32.1 | 33.6 | 35.8 |
| 18 Min. | 32.1 | 33.7 | 34.6 | 32.0 | 33.5 | 34.8 | 31.8 | 33.4 | 35.0 | 32.1 | 33.9 | 34.9 | 31.9 | 33.1 | 35.4 |
| 20 Max. | 33.3 | 34.4 | 35.5 | 33.7 | 34.4 | 35.8 | 32.6 | 34.2 | 35.9 | 33.0 | 34.4 | 35.5 | 32.5 | 34.0 | 36.0 |
| 20 Min. | 32.5 | 33.3 | 34.5 | 32.4 | 33.6 | 35.1 | 31.7 | 33.3 | 34.9 | 32.3 | 33.7 | 35.0 | 31.8 | 33.2 | 35.8 |
| 21 Max. | 33.8 | 34.3 | 35.8 | 33.3 | 34.3 | 35.9 | 32.6 | 34.3 | 35.8 | 33.0 | 34.4 | 35.7 | 32.3 | 33.8 | 36.3 |
| 21 Min. | 33.0 | 33.9 | 35.1 | 33.2 | 34.1 | 35.2 | 32.0 | 33.9 | 35.3 | 32.7 | 34.1 | 35.0 | 31.9 | 33.2 | 35 7 |
| 22 Max. | 33.6 | 34.3 | 35.7 | 33.5 | 34.6 | 35.7 | 32.2 | 34.2 | 35.8 | 33.0 | 34.3 | 35.3 | 32.3 | 33.7 | 35.9 |
| 22 Min. | 33.0 | 33.9 | 34.9 | 32.9 | 33.8 | 35.1 | 31.7 | 33.4 | 35.0 | 32.4 | 33.8 | 34.8 | 31.7 | 33.1 | 35.3 |
| 23 Max. | 33.3 | 34.2 | 35.6 | 33.2 | 34.2 | 35.6 | 32.1 | 33.9 | 35.3 | 32.8 | 34.3 | 35.2 | 32.1 | 33.4 | 35.9 |
| 23 Min. | 33.0 | 34.0 | 35.2 | 32.9 | 34.0 | 35.3 | 31.9 | 33.7 | 35.1 | 32.8 | 34.0 | 35.1 | 31.9 | 33.2 | 35.4 |
| 24 Max. | 33.3 | 34.2 | 35.6 | 33.1 | 34.1 | 35.5 | 32.2 | 34.1 | 35.4 | 33.0 | 34.6 | 35.4 | 32.2 | 33.7 | 36.1 |
| 24 Min. | 33.0 | 33.8 | 35.1 | 32.9 | 33.9 | 35.1 | 31.8 | 33.7 | 35.1 | 32.6 | 33.9 | 34.9 | 31.8 | 33.2 | 35.4 |
| 25 Max. | 33.3 | 34.2 | 35.6 | 33.2 | 34.1 | 35.7 | 32.1 | 34.1 | 35.4 | 33.1 | 34.4 | 35.4 | 32.2 | 33.6 | 35.9 |
| 25 Min. | 33.2 | 34.0 | 35.1 | 33.0 | 34.0 | 35.3 | 32.0 | 33.9 | 35.3 | 32.7 | 33.9 | 35.0 | 31.9 | 33.2 | 35.7 |
| 27 Max. | 33.3 | 34.0 | 35.3 | 33.0 | 34.0 | 35.2 | 31.9 | 34.0 | 35.1 | 32.9 | 34.1 | 35.1 | 31.9 | 33.2 | 35.7 |
| 27 Min. | 33.0 | 33.8 | 35.0 | 32.7 | 33.9 | 35.1 | 31.9 | 33.9 | 35.0 | 32.7 | 33.9 | 34.9 | 31.7 | 33.0 | 35.3 |
| 28 Max. | 32.7 | 33.6 | 35.1 | 32.1 | 33.7 | 35.1 | 32.2 | 34.0 | 35.3 | 32.9 | 34.3 | 35.4 | 32.2 | 33.3 | 35.9 |
| 28 Min. | 32.2 | 33.2 | 34.8 | 31.7 | 33.1 | 34.9 | 31.7 | 33.5 | 34.9 | 32.3 | 33.8 | 34.8 | 31.7 | 33.0 | 35.3 |
| 29 Max. | 31.6 | 33.2 | 35.1 | 30.2 | 33.0 | 35.1 | 31.8 | 34.0 | 35.3 | 32.2 | 34.1 | 35.1 | 31.2 | 33.3 | 35.8 |
| 29 Min. | 30.9 | 32.7 | 34.3 | 29.1 | 32.3 | 34.4 | 31.2 | 33.7 | 35.0 | 31.8 | 33.8 | 34.7 | 30.8 | 33.2 | 35.5 |
| 30 Max. | 31.2 | 32.4 | 34.2 | 31.1 | 32.2 | 34.3 | 31.2 | 33.3 | 34.9 | 31.4 | 33.3 | 34.4 | 30.9 | 33.0 | 35.2 |
| 30 Min. | 30.8 | 32.0 | 33.9 | 30.3 | 32.0 | 34.1 | 30.9 | 33.0 | 34.7 | 31.2 | 33.1 | 34.1 | 30.8 | 32.8 | 34 9 |
| 31 Max. | 31.8 | 32.8 | 34.0 | 31.5 | 32.3 | 34.1 | 31.3 | 33.3 | 34.9 | 31.9 | 33.3 | 34.4 | 31.4 | 33.1 | 35.3 |
| 31 Min. | 31.5 | 32 3 | 33.9 | 31.1 | 32.0 | 33.8 | 31.0 | 33.1 | 34.6 | 31.4 | 33.0 | 34.2 | 31.2 | 32.8 | 35.1 |
| Ave. Max. | 32.58 | 33.56 | 35.00 | 32.30 | 33.56 | 35.19 | 31.80 | 33.81 | 35.33 | 32.34 | 33.96 | 35.08 | 31.93 | 33.53 | 35.93 |
| Ave. Min. | 32.20 | 33.20 | 34.64 | 31.94 | 33.24 | 34.89 | 31.47 | 33.49 | 35.03 | 32.01 | 33.64 | 34.78 | 31.62 | 33.20 | 35.62 |
| Ave. Range | 0.38 | 0.36 | 0.36 | 0.36 | 0.32 | 0.30 | 0.33 | 0.32 | 0.30 | 0.33 | 0.34 | 0.30 | 0.31 | 0.33 | 0.31 |

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TABLE 41.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, FEBRUARY, 1913.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max | 30.0 | 32.7 | 34.2 | 31.7 | 32.9 | 34.3 | 31.3 | 33.3 | 34.9 | 31.7 | 33.3 | 34.6 | 30.0 | 33.2 | 35.3 |
| 1 Min | 29.1 | 31.9 | 34.1 | 30.0 | 32.7 | 34.3 | 30.8 | 33.2 | 34.9 | 31.0 | 33.2 | 34.3 | 29.4 | 33.0 | 35.2 |
| 3 Max | 30.0 | 31.0 | 33.4 | 30.0 | 31.3 | 33.8 | 29.8 | 32.9 | 34.3 | 29.8 | 32.8 | 33.9 | 29.6 | 32.7 | 35.2 |
| 3 Min | 27.7 | 29.9 | 32.9 | 26.2 | 30.7 | 33.4 | 28.9 | 32.2 | 34.1 | 29.0 | 32.2 | 33.6 | 27.2 | 32.2 | 34.8 |
| 4 Max | 28.7 | 30.3 | 33.2 | 27.3 | 30.8 | 33.8 | 29.2 | 32.8 | 34.4 | 29.5 | 32.7 | 34.0 | 28.0 | 32.8 | 35.1 |
| 4 Min | 27.0 | 30.0 | 33.1 | 25.0 | 30.3 | 33.5 | 28.8 | 32.7 | 34.2 | 28.8 | 32.2 | 33.7 | 27.0 | 32.8 | 35.0 |
| 5 Max | 25.8 | 28.5 | 32.8 | 22.9 | 28.5 | 33.2 | 26.9 | 32.1 | 33.9 | 27.0 | 31.9 | 33.2 | 25.0 | 32.2 | 34.8 |
| 5 Min | 23.3 | 27.3 | 32.4 | 19.9 | 27.8 | 33.0 | 25.8 | 31.9 | 33.8 | 26.1 | 31.8 | 33.1 | 23.1 | 31.9 | 34.4 |
| 6 Max | 24.7 | 27.0 | 32.1 | 22.2 | 27.0 | 33.0 | 25.8 | 31.8 | 33.9 | 25.8 | 31.7 | 33.2 | 23.3 | 32.0 | 34.6 |
| 6 Min | 22.1 | 25.6 | 31.8 | 18.3 | 26 0 | 32.3 | 23.9 | 31.2 | 33.1 | 24.4 | 31.1 | 32.8 | 21 0 | 31.4 | 34.3 |
| 7 Max | 26.9 | 28.1 | 31.8 | 25.3 | 28.8 | 32.8 | 26.7 | 31.4 | 33.7 | 26.9 | 31.1 | 33.0 | 25.1 | 31.8 | 34.6 |
| 7 Min | 25.0 | 27.3 | 31.7 | 22.8 | 27.4 | 32.7 | 25.3 | 31.2 | 33.3 | 25.8 | 30.9 | 32.7 | 23.3 | 31.4 | 34.3 |
| 8 Max | 27.9 | 28.6 | 31.3 | 28.0 | 29.3 | 32.2 | 27.2 | 31.1 | 33.3 | 27.0 | 30.4 | 32.8 | 26.8 | 31.4 | 34.2 |
| 8 Min | 25.8 | 28.0 | 31.1 | 24.0 | 28.3 | 32.0 | 25.9 | 30.7 | 32.7 | 26.1 | 29.9 | 31.9 | 24.4 | 31.0 | 33.9 |
| 10 Max | 27.7 | 28.1 | 31.6 | 28.1 | 28.7 | 32.4 | 26.8 | 30.8 | 33.2 | 26.9 | 30.3 | 32.4 | 26.3 | 31.1 | 34.0 |
| 10 Min | 24.1 | 26.2 | 30.9 | 21.8 | 27.0 | 31.6 | 24.8 | 30.1 | 32.5 | 25.2 | 29.8 | 31.7 | 22.9 | 30.2 | 33.3 |
| 11 Max | 28.9 | 29.7 | 31.0 | 29.2 | 30.0 | 31.3 | 28.0 | 30.0 | 32.9 | 28.6 | 30.0 | 31.4 | 28.2 | 30.4 | 33.3 |
| 11 Min | 27.2 | 28.3 | 30.2 | 27.8 | 28.9 | 31.1 | 27.1 | 29.8 | 31.5 | 27.4 | 29.6 | 31.0 | 27.3 | 29.8 | 32.8 |
| 12 Max | 25.9 | 27.4 | 31.0 | 24.2 | 28.0 | 32.0 | 26.1 | 30.2 | 32.8 | 26.4 | 30.0 | 31.8 | 24.0 | 30.0 | 33.7 |
| 12 Min | 23.3 | 26.3 | 30.9 | 21.0 | 27.2 | 31.2 | 24.9 | 30.0 | 31.8 | 25.3 | 29.4 | 31.2 | 22.2 | 29.8 | 33.0 |
| 13 Max | 25.0 | 26.3 | 30.9 | 23.3 | 26.7 | 31.2 | 24.8 | 29.9 | 32.6 | 25.0 | 29.3 | 31.8 | 23.0 | 28.8 | 33.3 |
| 13 Min | 21.1 | 24.2 | 30.2 | 17.3 | 25.1 | 30.7 | 22.3 | 29.2 | 32.1 | 23.1 | 28.7 | 31.1 | 19.1 | 28.0 | 32.9 |
| 14 Max | 27.7 | 27.8 | 30.4 | 28.1 | 28.2 | 31.0 | 26.1 | 29.2 | 32.4 | 26.0 | 28.8 | 31.1 | 25.9 | 28.1 | 32.9 |
| 14 Min | 22.9 | 25.8 | 30.1 | 20.1 | 26.7 | 30.7 | 24.0 | 28 9 | 31.9 | 24.5 | 28.4 | 30.9 | 21.8 | 27.9 | 32.3 |
| 15 Max | 29.2 | 29.8 | 30.9 | 29.8 | 30.0 | 31.2 | 28.2 | 29.2 | 31.7 | 28.2 | 29.6 | 30.9 | 28.5 | 29.3 | 32.8 |
| 15 Min | 28.9 | 29.4 | 30.4 | 28.6 | 29.9 | 30.9 | 27.7 | 29.4 | 31.3 | 27.4 | 29.0 | 30.7 | 27.7 | 29.0 | 32.0 |
| 17 Max | 29.9 | 30.2 | 31.2 | 29.9 | 30.3 | 31.2 | 28.8 | 30.1 | 31.7 | 28.9 | 30.0 | 31.0 | 28.9 | 29.8 | 32.5 |
| 17 Min | 29.0 | 29.9 | 31.0 | 28.4 | 29.9 | 31.2 | 28.3 | 30.0 | 31.4 | 28.4 | 29.8 | 30.9 | 27 9 | 29.7 | 32.0 |
| 18 Max | 29.7 | 29.9 | 31.2 | 29.8 | 30.1 | 31.3 | 28.2 | 30.0 | 31.6 | 28.9 | 30.0 | 31.1 | 28.4 | 29.9 | 32.3 |
| 18 Min | 27.1 | 28.9 | 30.9 | 25.8 | 28.7 | 31.2 | 27.7 | 29.9 | 31.3 | 28.0 | 29.9 | 30.7 | 26.2 | 29.3 | 32.2 |
| 19 Max | 30.8 | 30.9 | 31.3 | 30.9 | 31.2 | 31.7 | 29.4 | 30.3 | 31.7 | 29.7 | 30.2 | 31.2 | 30.6 | 30.6 | 32.7 |
| 19 Min | 30.2 | 30.4 | 30.9 | 30.4 | 30.8 | 31.2 | 29.0 | 29.9 | 31.4 | 29.0 | 29.4 | 30.8 | 29.8 | 29.8 | 32.2 |
| 20 Max | 31.9 | 31.7 | 31.7 | 31.7 | 31.9 | 32.0 | 30.1 | 31.1 | 31.9 | 30.7 | 30.9 | 31.4 | 30.9 | 30.9 | 32.5 |
| 20 Min | 31.3 | 31.3 | 31.2 | 31.2 | 31.3 | 31.3 | 29.8 | 30.8 | 31.3 | 30.1 | 30.6 | 31.0 | 30.3 | 30.1 | 32.2 |
| 21 Max | 32.4 | 32.9 | 32.3 | 32.1 | 32.5 | 32.5 | 31.1 | 31.7 | 32.8 | 31.8 | 31.7 | 32.2 | 31.7 | 31.3 | 33.1 |
| 21 Min | 32.0 | 32.1 | 32.1 | 31.9 | 32.0 | 32.2 | 30.8 | 31.4 | 32.3 | 31.2 | 31.2 | 31.8 | 31.2 | 31.1 | 32.7 |
| 22 Max | 31.9 | 32.1 | 32.6 | 32.0 | 32.3 | 32.2 | 31.0 | 31.6 | 32.6 | 31.7 | 31.6 | 32.2 | 31.9 | 31.3 | 33.2 |
| 22 Min | 31.8 | 31.8 | 31.7 | 31.3 | 31.7 | 31.8 | 30.3 | 31.0 | 31.9 | 31.0 | 31.0 | 31.3 | 30.9 | 30.8 | 32.4 |
| 24 Max | 32.0 | 32.1 | 32.1 | 31.8 | 32.0 | 32.2 | 31.0 | 31.3 | 32.1 | 31.7 | 31.7 | 31.9 | 31.4 | 31.2 | 32.9 |
| 24 Min | 32.0 | 31.9 | 32.0 | 31.7 | 32.0 | 32.1 | 31.0 | 31.3 | 32.0 | 31.6 | 31.6 | 31.8 | 31.3 | 31.1 | 32.8 |
| 25 Max | 31.9 | 32.1 | 32.1 | 31.9 | 32.2 | 32.3 | 31.1 | 31.6 | 32.2 | 31.5 | 31.7 | 32.0 | 31.6 | 31.3 | 32.9 |
| 25 Min | 31.2 | 31.6 | 31.3 | 31.1 | 31.3 | 31.6 | 30.3 | 30.6 | 31.6 | 30.4 | 31.1 | 31.2 | 30.7 | 30.7 | 32.4 |
| 26 Max | 31.7 | 31.8 | 31.8 | 31.4 | 31.7 | 32.0 | 30.6 | 31.2 | 31.8 | 30.7 | 31.3 | 31.7 | 31.3 | 31.1 | 32.6 |
| 26 Min | 31.5 | 31.7 | 31.7 | 31.2 | 31.4 | 31.9 | 30.4 | 31.0 | 31.7 | 30.6 | 31.2 | 31.6 | 31.2 | 31.0 | 32.3 |
| 27 Max | 31.9 | 32.0 | 32.3 | 31.9 | 32.3 | 32.8 | 31.1 | 31.7 | 32.6 | 31.4 | 31.8 | 32.1 | 31.8 | 31.4 | 33.0 |
| 27 Min | 31.3 | 31.6 | 31.6 | 31.0 | 31.2 | 31.8 | 30.1 | 30.9 | 31.7 | 30.3 | 30.9 | 31.2 | 30.8 | 30.7 | 32.9 |
| 28 Max | 31.9 | 32.2 | 32.0 | 31.7 | 31.9 | 32.3 | 30.7 | 31.3 | 32.0 | 31.0 | 31.4 | 31.9 | 31.3 | 31.2 | 32.7 |
| 28 Min | 31.6 | 31.7 | 31.7 | 31.3 | 31.7 | 31.9 | 30.3 | 31.1 | 31.8 | 30.6 | 31.1 | 31.4 | 30.9 | 30.8 | 31.9 |
| Ave. Max | 29.35 | 30.13 | 31.88 | 28.97 | 30.36 | 32.28 | 28.75 | 31.13 | 32.76 | 29.03 | 31.01 | 32.20 | 28.48 | 30.99 | 33.51 |
| Ave. Min | 27.77 | 29.30 | 31.50 | 26.59 | 29.58 | 31.90 | 27.84 | 30.77 | 32.32 | 28.14 | 30.58 | 31.77 | 26.98 | 30.56 | 33.09 |
| Ave. Diff | 1.58 | 0.83 | 0.38 | 2.38 | 0.78 | 0.38 | 0.91 | 0.38 | 0.44 | 0.89 | 0.43 | 0.43 | 1.50 | 0.43 | 0.42 |

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TABLE 42.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT WITH SAND, MARCH, 1913.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 31.6 | 31.8 | 31.9 | 31.6 | 31.7 | 32.2 | 30.2 | 31.1 | 31.8 | 30.7 | 31.5 | 31.6 | 31.1 | 31.0 | 32.4 |
| 1 Min.... | 31.4 | 31.6 | 31.7 | 31.2 | 31.6 | 32.0 | 30.1 | 31.0 | 31.7 | 30.4 | 31.1 | 31.4 | 30.8 | 30.7 | 32.1 |
| 3 Max.... | 31.7 | 31.8 | 31.9 | 30.9 | 31.7 | 32.3 | 30.0 | 31.2 | 31.8 | 30.3 | 31.2 | 31.7 | 30.2 | 30.9 | 32.4 |
| 3 Min.... | 31.4 | 31.7 | 31.8 | 30.8 | 31.6 | 32.1 | 30.0 | 31.0 | 31.7 | 30.2 | 31.0 | 31.4 | 30.0 | 30.8 | 32.3 |
| 4 Max.... | 31.8 | 32.0 | 32.3 | 31.3 | 31.9 | 32.7 | 30.5 | 31.6 | 32.3 | 31.0 | 31.6 | 32.0 | 30.7 | 31.2 | 32.8 |
| 4 Min.... | 31.7 | 31.9 | 32.1 | 31.1 | 31.6 | 32.2 | 30.4 | 31.3 | 32 1 | 30.7 | 31.4 | 31.8 | 30.4 | 31.0 | 32.6 |
| 5 Max.... | 32.2 | 32.4 | 32.8 | 31.0 | 31.9 | 32.9 | 30.3 | 31.4 | 32.2 | 30.9 | 31.6 | 31.9 | 30.3 | 31.1 | 32.7 |
| 5 Min.... | 31.4 | 31.8 | 32.0 | 30.6 | 31.6 | 32.3 | 29.9 | 31.1 | 31.9 | 30.4 | 31.1 | 31.6 | 30.0 | 30.8 | 32.4 |
| 6 Max.... | 31.8 | 32.0 | 32.4 | 31.1 | 31.9 | 32.9 | 30.3 | 31.3 | 32.1 | 30.7 | 31.6 | 31.9 | 30.3 | 31.0 | 32.8 |
| 6 Min.... | 31.3 | 31.7 | 31.9 | 30.7 | 31.4 | 32.4 | 29.9 | 31.0 | 31.7 | 30.2 | 31.1 | 31.6 | 29.8 | 30.6 | 32.4 |
| 7 Max.... | 31.9 | 32.1 | 32.7 | 31.0 | 31.9 | 32.9 | 30.2 | 31.4 | 32.3 | 30.7 | 31.7 | 32.2 | 29.9 | 31.1 | 32.9 |
| 7 Min.... | 31.5 | 31.9 | 32.2 | 30.4 | 31.6 | 32.6 | 29.9 | 31.1 | 32.0 | 30.2 | 31.3 | 31.8 | 29.0 | 30.8 | 32.5 |
| 8 Max.... | 31.7 | 32.2 | 32.7 | 30.8 | 31.7 | 32.7 | 30.0 | 31.3 | 32.3 | 30.3 | 31.6 | 32.1 | 29.0 | 30.9 | 32.9 |
| 8 Min.... | 31.3 | 31.9 | 32.4 | 30.3 | 31.3 | 32.7 | 29.8 | 31.2 | 32.0 | 30.1 | 31.2 | 31.9 | 28.9 | 30.7 | 32.7 |
| 10 Max.... | 31.8 | 32.1 | 32.8 | 31.8 | 32.1 | 32.7 | 30.7 | 31.3 | 32.3 | 31.3 | 31.7 | 32.0 | 31.0 | 31.1 | 32.9 |
| 10 Min.... | 31.6 | 31.9 | 32.4 | 31.4 | 31.9 | 32.3 | 30.5 | 31.2 | 32.0 | 31 1 | 31.4 | 31.9 | 30.9 | 31.0 | 32.6 |
| 11 Max.... | 32.0 | 32.5 | 32.9 | 32.0 | 32.3 | 32.9 | 31.0 | 31.9 | 32.7 | 31.7 | 31.9 | 32.2 | 31.5 | 31.3 | 33.0 |
| 11 Min.... | 31.6 | 31.7 | 32.2 | 31.3 | 31.6 | 32.0 | 30.2 | 31 0 | 31.9 | 31.1 | 31.4 | 32.0 | 31.0 | 30.9 | 32.7 |
| 12 Max.... | 32.7 | 32.8 | 33.1 | 32.2 | 32.6 | 33.1 | 31.2 | 31.9 | 32.9 | 31.8 | 32.1 | 32.7 | 31.9 | 31.7 | 33.3 |
| 12 Min.... | 32.0 | 32.1 | 32.9 | 31.9 | 32.1 | 32.5 | 30.9 | 31.7 | 32.6 | 31.4 | 31.9 | 32.3 | 31.4 | 31.4 | 32.9 |
| 13 Max.... | 32.7 | 32.9 | 33.0 | 32.0 | 32.5 | 33.0 | 31.3 | 31.8 | 32.7 | 31.9 | 32.0 | 32.7 | 31.8 | 31.5 | 33.0 |
| 13 Min.... | 32.0 | 32.4 | 32.8 | 31.8 | 32.1 | 32.8 | 30.9 | 31.6 | 32.4 | 31.7 | 31.9 | 32.6 | 31.6 | 31.4 | 32.9 |
| 15 Max.... | 33.7 | 32.7 | 33.2 | 33.4 | 32.6 | 33.3 | 32.1 | 32.1 | 32.9 | 33.0 | 32.4 | 32.9 | 32.4 | 31.9 | 33.3 |
| 15 Min.... | 32.3 | 32.2 | 32.7 | 32.0 | 32.0 | 32.7 | 31.4 | 31.7 | 32.2 | 32.2 | 31.9 | 32.2 | 31.9 | 31.4 | 32.9 |
| 17 Max.... | 32.0 | 32.6 | 33.1 | 31.8 | 32.3 | 33.2 | 31.8 | 31.9 | 32.8 | 32.3 | 32.3 | 32.7 | 32.4 | 31.8 | 33.2 |
| 17 Min.... | 31.5 | 32.1 | 32.7 | 31.1 | 31.8 | 32.8 | 31.4 | 31.7 | 32.2 | 31.9 | 31.8 | 32.2 | 31.8 | 31.3 | 32.8 |
| 18 Max.... | 32.7 | 32.3 | 32.8 | 33.8 | 32.1 | 32.9 | 31.6 | 31.8 | 32.3 | 32.0 | 31.9 | 32.3 | 31.9 | 31.6 | 32.9 |
| 18 Min.... | 31.7 | 32.2 | 32.7 | 31.3 | 31.9 | 32.7 | 31.3 | 31.4 | 32.2 | 31.9 | 31.8 | 32.0 | 31.7 | 31.1 | 32.7 |
| 19 Max.... | 44.7 | 35.9 | 33.2 | 46.0 | 36.0 | 33.2 | 35.1 | 31.8 | 32.5 | 36.1 | 32.6 | 32.9 | 32.4 | 31.9 | 33.3 |
| 19 Min.... | 32.1 | 32.7 | 32.7 | 32.1 | 32.4 | 32.8 | 31.3 | 31.3 | 32.0 | 31.9 | 31.7 | 32.2 | 31.7 | 31.2 | 32.7 |
| 20 Max.... | 44.7 | 39.2 | 35.4 | 45.8 | 39.4 | 35.9 | 37.5 | 32.0 | 32.8 | 39.7 | 32.7 | 32.8 | 32.3 | 31.8 | 33.1 |
| 20 Min.... | 40.9 | 37.1 | 34.8 | 40.9 | 37.1 | 34.9 | 34.7 | 31.8 | 32.6 | 36.3 | 31.9 | 32.6 | 32.0 | 31.4 | 33.0 |
| 21 Max.... | 37.9 | 36.6 | 35.8 | 38.2 | 36.6 | 36.1 | 34.8 | 32.2 | 32.9 | 35.9 | 32.4 | 32.8 | 32.3 | 32.1 | 33.4 |
| 21 Min.... | 34.7 | 36 0 | 35 6 | 34.8 | 35.8 | 35.6 | 32.7 | 31.9 | 32.7 | 34.0 | 32.3 | 32.7 | 32.1 | 31.8 | 33.2 |
| 22 Max.... | 35.0 | 34.2 | 34.8 | 35.7 | 34.4 | 35.1 | 32.4 | 32.2 | 33.1 | 33.9 | 32.6 | 32.9 | 32.6 | 32.1 | 33.6 |
| 22 Min.... | 32.9 | 33.9 | 34.3 | 32.4 | 33.7 | 34.2 | 31.9 | 32.0 | 32.8 | 32.6 | 32.2 | 32.7 | 32.0 | 31.8 | 32.9 |
| 24 Max.... | 48.9 | 41.7 | 36.9 | 46.0 | 40.3 | 36.7 | 42.1 | 31.7 | 32.7 | 43.0 | 32.2 | 32.9 | 32.1 | 31.8 | 33.3 |
| 24 Min.... | 44.2 | 37.8 | 34.7 | 44.6 | 37.1 | 34.7 | 39.8 | 31.5 | 32.0 | 40.9 | 31.9 | 32.2 | 31.8 | 31.5 | 32.9 |
| 25 Max.... | 36.3 | 36.6 | 36.0 | 36.1 | 36.4 | 37.8 | 34.1 | 32.0 | 33.0 | 36.1 | 32.7 | 32.8 | 32.1 | 31.9 | 33.2 |
| 25 Min.... | 34.3 | 36.4 | 37.2 | 34.2 | 36.4 | 37.0 | 32.2 | 31.8 | 32.8 | 33.8 | 32.6 | 32.7 | 31.9 | 31.5 | 33.1 |
| 26 Max.... | 33.2 | 35.7 | 36.3 | 32.9 | 35.2 | 36.2 | 31.7 | 31.9 | 33.0 | 32.9 | 33.2 | 33.6 | 31.7 | 31.3 | 32.9 |
| 26 Min.... | 32.4 | 34.2 | 35.2 | 31.9 | 34.1 | 35.2 | 31.2 | 31.3 | 32.6 | 32.1 | 32.7 | 32.9 | 31.6 | 31.1 | 32.8 |
| 27 Max.... | 33.3 | 34.8 | 35.8 | 32.9 | 34.7 | 35.7 | 31.8 | 31.9 | 33.3 | 32.8 | 33.3 | 33.7 | 32.1 | 31.7 | 33.3 |
| 27 Min.... | 32.1 | 33.7 | 34.4 | 31.8 | 33.4 | 34.7 | 31.0 | 31.2 | 32.3 | 31.8 | 32.6 | 33.0 | 31.3 | 30.9 | 33.9 |
| 28 Max.... | 33.0 | 34.2 | 35.1 | 32.7 | 34.1 | 35.0 | 31.7 | 31.9 | 33.2 | 32.8 | 33.4 | 33.9 | 32.1 | 32.1 | 33.6 |
| 28 Min.... | 32.6 | 33.8 | 34.7 | 32.1 | 33.6 | 34.7 | 31.2 | 31.4 | 32.7 | 32.2 | 32.9 | 33.1 | 31.3 | 30.7 | 32.8 |
| 29 Max.... | 32.9 | 34.1 | 34.9 | 32.6 | 33.9 | 34.7 | 31.6 | 32.3 | 33.3 | 32.9 | 33.8 | 34.1 | 32.2 | 31.8 | 33.4 |
| 29 Min.... | 32.2 | 33.2 | 34.1 | 31.7 | 33.1 | 33.8 | 30.2 | 31.7 | 32.9 | 32.5 | 33.4 | 33.6 | 31.9 | 31.7 | 33.3 |
| 31 Max.... | 44.3 | 40.2 | 37.8 | 44.7 | 39.8 | 37.2 | 41.1 | 31.3 | 33.0 | 42.3 | 37.2 | 36.0 | 32.2 | 31.4 | 33.3 |
| 31 Min.... | 41.2 | 39.2 | 37.7 | 40.4 | 38.4 | 36.9 | 38.8 | 31.1 | 32.4 | 40.6 | 36.8 | 35.3 | 31.6 | 30.8 | 33.4 |
| Ave. Max.. | 34.98 | 34.30 | 34.06 | 34.81 | 34.08 | 34.13 | 32.61 | 31.73 | 32.65 | 33.48 | 33.45 | 32.77 | 31.54 | 31.52 | 33.08 |
| Ave. Min.. | 33.29 | 33.41 | 33.52 | 32.91 | 33.17 | 33.54 | 31.66 | 31.40 | 32.26 | 32.49 | 32.05 | 32.38 | 31.14 | 31.13 | 32.74 |
| Ave. Range | 1.69 | 0.89 | 0.54 | 1.90 | 0.91 | 0.59 | 0.95 | 0.33 | 0.39 | 0.99 | 0.40 | 0.38 | 0.40 | 0.39 | 0.34 |

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TABLE 43.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, APRIL, 1913.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 46.7 | 42.2 | 39.4 | 47.7 | 42.1 | 39.2 | 42.7 | 33.9 | 34.9 | 43.7 | 38.8 | 37.8 | 32.8 | 32.5 | 34.6 |
| 1 Min. | 38.9 | 39.0 | 38.7 | 37.9 | 38.5 | 38.7 | 35.0 | 32.1 | 34.5 | 37.8 | 38.3 | 37.7 | 32.2 | 31.6 | 33.6 |
| 2 Max. | 41.8 | 40.7 | 39.8 | 41.1 | 40.3 | 39.7 | 39.6 | 37.7 | 36.8 | 40.2 | 39.2 | 38.2 | 32.6 | 32.2 | 33.9 |
| 2 Min. | 39.4 | 40.0 | 39.3 | 38.9 | 39.6 | 38.9 | 37.7 | 36.8 | 35.7 | 38.9 | 38.7 | 37.8 | 32.2 | 31.8 | 33.7 |
| 3 Max. | 51.3 | 43.0 | 40.1 | 50.8 | 42.2 | 40.0 | 47.4 | 39.2 | 38.1 | 46.5 | 39.3 | 38.4 | 33.2 | 32.0 | 34.0 |
| 3 Min. | 40.6 | 40.2 | 39.8 | 40.1 | 39.5 | 39.6 | 39.0 | 38.1 | 37.8 | 39.9 | 38.8 | 38.0 | 32.8 | 31.6 | 33.9 |
| 4 Max. | 52.9 | 47.2 | 43.8 | 52.0 | 46.8 | 44.0 | 51.0 | 43.8 | 40.5 | 50.3 | 44.2 | 41.4 | 35.4 | 32.7 | 34.9 |
| 4 Min. | 47.8 | 46.7 | 42.0 | 47.1 | 45.2 | 41.6 | 48.8 | 42.4 | 39.2 | 48.9 | 42.5 | 40.2 | 34.6 | 31.7 | 34.0 |
| 5 Max. | 43.0 | 42.0 | 42.8 | 43.1 | 42.1 | 42.9 | 41.9 | 43.1 | 41.2 | 41.6 | 43.0 | 42.1 | 33.2 | 32.3 | 34.9 |
| 5 Min. | 37.4 | 41.1 | 41.7 | 37.7 | 41.2 | 42.0 | 39.2 | 41.9 | 40.6 | 40.0 | 41.6 | 41.2 | 33.0 | 32.0 | 34.7 |
| 7 Max. | 44.2 | 41.5 | 41.0 | 45.2 | 41.6 | 40.8 | 41.9 | 40.1 | 39.9 | 41.1 | 39.8 | 40.0 | 33.3 | 32.2 | 35.3 |
| 7 Min. | 36.3 | 38.6 | 40.0 | 36.1 | 39.0 | 40.1 | 36.1 | 39.4 | 39.7 | 36.3 | 39.0 | 39.4 | 33.0 | 31.8 | 35.1 |
| 8 Max. | 48.0 | 42.1 | 40.3 | 48.6 | 41.4 | 40.6 | 43.3 | 39.8 | 39.8 | 42.7 | 39.2 | 39.6 | 33.2 | 32.1 | 35.8 |
| 8 Min. | 35.1 | 38.8 | 39.6 | 35.1 | 38.4 | 39.9 | 36.0 | 39.0 | 39.3 | 36.1 | 38.7 | 39.3 | 32.6 | 31.7 | 35.1 |
| 9 Max. | 42.1 | 40.4 | 40.6 | 42.2 | 40.4 | 40.4 | 39.0 | 39.6 | 39.2 | 39.5 | 39.5 | 39.0 | 33.1 | 31.9 | 35.2 |
| 9 Min. | 37.9 | 39.6 | 40.0 | 37.8 | 39.6 | 39.1 | 36.6 | 38.9 | 39.0 | 37.4 | 39.0 | 38.9 | 32.3 | 31.4 | 35.0 |
| 10 Max. | 44.9 | 41.0 | 40.2 | 44.7 | 41.0 | 40.4 | 42.4 | 39.2 | 39.3 | 42.2 | 39.2 | 39.2 | 33.9 | 31.9 | 35.2 |
| 10 Min. | 39.2 | 39.9 | 40.0 | 38.9 | 39.8 | 40.1 | 37.8 | 39.1 | 39.1 | 38.6 | 39.1 | 39.0 | 32.8 | 31.7 | 35.0 |
| 11 Max. | 43.2 | 42.7 | 41.3 | 43.1 | 42.5 | 41.2 | 42.8 | 41.0 | 39.8 | 42.9 | 41.1 | 40.2 | 35.4 | 32.1 | 35.9 |
| 11 Min. | 43.0 | 42.2 | 41.2 | 42.8 | 41.9 | 41.0 | 42.2 | 40.7 | 39.4 | 42.6 | 40.9 | 40.0 | 34.7 | 31.8 | 35.0 |
| 12 Max. | 41.4 | 41.2 | 41.1 | 41.2 | 41.1 | 41.0 | 41.0 | 41.0 | 40.3 | 41.0 | 41.2 | 40.7 | 34.6 | 32.2 | 35.7 |
| 12 Min. | 40.1 | 41.1 | 40.9 | 39.6 | 40.8 | 40.8 | 40.0 | 40.7 | 40.1 | 40.6 | 40.8 | 40.3 | 34.0 | 31.8 | 35.2 |
| 14 Max. | 52.4 | 45.4 | 42.6 | 53.3 | 44.9 | 42.2 | 48.0 | 42.0 | 41.0 | 47.0 | 41.9 | 41.3 | 35.4 | 32.2 | 36.3 |
| 14 Min. | 38.8 | 42.0 | 41.8 | 38.2 | 41.3 | 41.7 | 39.3 | 41.3 | 40.7 | 39.9 | 41.2 | 41.0 | 34.7 | 31.7 | 36.1 |
| 15 Max. | 57.2 | 46.3 | 42.7 | 57.7 | 45.4 | 42.7 | 51.8 | 42.2 | 41.2 | 49.7 | 42.1 | 41.8 | 36.1 | 32.4 | 36.8 |
| 15 Min. | 37.5 | 42.0 | 42.0 | 37.3 | 41.8 | 42.0 | 38.3 | 41.9 | 41.1 | 39.1 | 41.3 | 41.4 | 34.9 | 32.3 | 36.1 |
| 16 Max. | 59.1 | 48.9 | 44.1 | 58.8 | 47.8 | 43.9 | 53.8 | 43.4 | 41.8 | 52.3 | 43.7 | 42.2 | 37.3 | 32.3 | 37.0 |
| 16 Min. | 43.0 | 44.7 | 43.3 | 42.1 | 44.1 | 43.0 | 42.2 | 42.9 | 41.1 | 42.8 | 42.9 | 41.9 | 36.0 | 32.1 | 36.3 |
| 17 Max. | 61.2 | 50.5 | 45.7 | 60.3 | 48.8 | 45.0 | 55.9 | 44.7 | 43.0 | 54.3 | 45.0 | 43.7 | 38.0 | 32.7 | 37.7 |
| 17 Min. | 42.9 | 46.1 | 44.8 | 41.7 | 45.0 | 44.4 | 42.1 | 44.3 | 42.9 | 43.6 | 44.3 | 43.1 | 36.7 | 32.4 | 37.0 |
| 18 Max. | 63.2 | 53.9 | 47.2 | 62.2 | 51.8 | 46.8 | 58.6 | 46.9 | 44.0 | 57.2 | 47.3 | 44.2 | 40.7 | 32.8 | 37.6 |
| 18 Min. | 50.0 | 49.2 | 46.2 | 49.0 | 48.3 | 46.0 | 48.3 | 46.1 | 43.6 | 49.0 | 46.4 | 44.7 | 39.2 | 32.7 | 37.0 |
| 19 Max. | 56.3 | 51.2 | 48.6 | 55.8 | 50.2 | 47.9 | 52.9 | 48.3 | 45.1 | 52.6 | 48.9 | 46.7 | 40.9 | 33.2 | 38.8 |
| 19 Min. | 46.0 | 48.6 | 47.7 | 45.9 | 48.0 | 47.1 | 45.9 | 47.4 | 45.0 | 47.3 | 47.4 | 46.1 | 40.1 | 33.0 | 37.0 |
| 21 Max. | 53.9 | 48.0 | 46.8 | 53.2 | 47.3 | 46.1 | 50.6 | 46.0 | 45.0 | 49.8 | 46.3 | 45.9 | 41.7 | 40.0 | 41.7 |
| 21 Min. | 41.0 | 45.1 | 45.7 | 40.1 | 44.9 | 45.3 | 40.7 | 45.4 | 44.9 | 42.0 | 45.4 | 44.9 | 40.3 | 38.4 | 41.2 |
| 22 Max. | 61.4 | 51.6 | 47.0 | 60.7 | 50.3 | 46.6 | 57.4 | 46.8 | 45.0 | 56.1 | 46.5 | 45.4 | 50.2 | 42.0 | 42.8 |
| 22 Min. | 47.9 | 47.7 | 46.0 | 47.2 | 47.1 | 45.9 | 46.2 | 45.9 | 44.4 | 46.6 | 45.8 | 45.0 | 43.3 | 41.8 | 42.0 |
| 23 Max. | 68.3 | 56.9 | 50.3 | 68.9 | 56.0 | 49.8 | 63.9 | 50.9 | 46.8 | 62.3 | 50.9 | 48.4 | 53.7 | 46.0 | 44.4 |
| 23 Min. | 54.3 | 52.3 | 48.9 | 53.3 | 51.0 | 48.0 | 53.6 | 48.8 | 45.7 | 53.3 | 48.9 | 46.8 | 50.0 | 44.0 | 43.7 |
| 24 Max. | 68.1 | 58.7 | 51.8 | 68.0 | 57.4 | 51.2 | 64.8 | 52.2 | 48.1 | 63.2 | 52.4 | 49.4 | 56.4 | 47.8 | 45.6 |
| 24 Min. | 54.9 | 54.6 | 50.9 | 53.9 | 53.1 | 50.0 | 54.3 | 51.4 | 47.9 | 54.1 | 51.8 | 49.1 | 53.3 | 47.0 | 45.0 |
| 25 Max. | 58.7 | 56.8 | 53.5 | 58.4 | 56.2 | 52.8 | 57.9 | 54.1 | 50.3 | 58.0 | 54.3 | 52.1 | 56.1 | 50.7 | 47.9 |
| 25 Min. | 58.0 | 56.0 | 53.0 | 57.3 | 55.1 | 52.6 | 57.1 | 54.0 | 49.5 | 57.0 | 54.0 | 51.1 | 45.4 | 49.8 | 46.4 |
| 26 Max. | 50.6 | 52.7 | 52.3 | 50.4 | 52.2 | 51.7 | 51.0 | 53.0 | 50.6 | 51.7 | 53.1 | 51.9 | 53.6 | 51.0 | 48.7 |
| 26 Min. | 49.4 | 50.2 | 49.8 | 49.1 | 49.6 | 49.4 | 49.9 | 50.6 | 49.2 | 50.1 | 50.6 | 49.9 | 51.1 | 49.9 | 47.8 |
| 28 Max. | 50.8 | 47.0 | 46.5 | 52.2 | 47.1 | 46.5 | 49.6 | 47.0 | 48.0 | 48.7 | 46.8 | 47.3 | 47.0 | 48.3 | 48.6 |
| 28 Min. | 42.0 | 45.0 | 46.4 | 41.8 | 44.8 | 46.4 | 43.0 | 46.6 | 46.7 | 43.6 | 46.4 | 46.8 | 45.8 | 48.0 | 48.4 |
| 29 Max. | 58.6 | 49.6 | 46.6 | 60.0 | 49.6 | 46.9 | 54.3 | 46.9 | 46.8 | 52.2 | 46.6 | 46.9 | 48.5 | 47.9 | 48.2 |
| 29 Min. | 41.2 | 45.2 | 46.0 | 40.8 | 45.4 | 46.2 | 41.8 | 46.1 | 46.2 | 42.5 | 46.0 | 46.2 | 45.6 | 47.3 | 47.6 |
| 30 Max. | 65.9 | 54.0 | 48.6 | 66.4 | 53.5 | 48.5 | 60.7 | 48.5 | 46.9 | 58.2 | 48.0 | 47.1 | 51.9 | 47.7 | 47.6 |
| 30 Min. | 45.6 | 48.2 | 47.8 | 44.6 | 48.0 | 47.6 | 45.2 | 47.6 | 46.5 | 45.6 | 47.3 | 47.0 | 47.8 | 47.5 | 47.5 |
| Ave. Max. | 53.28 | 47.52 | 44.80 | 53.31 | 46.92 | 44.56 | 50.18 | 44.28 | 42.82 | 49.42 | 44.55 | 43.52 | 40.70 | 37.35 | 39.43 |
| Ave. Min. | 43.39 | 44.77 | 43.98 | 42.86 | 44.27 | 43.75 | 42.93 | 43.44 | 42.30 | 43.60 | 43.73 | 42.95 | 38.78 | 36.80 | 38.82 |
| Ave. Range | 9.89 | 2.75 | 0.82 | 10.45 | 2.65 | 0.81 | 7.23 | 0.84 | 0.52 | 5.82 | 0.82 | 0.57 | 1.92 | 0.55 | 0.61 |



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TABLE 44.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL. NOT COVERED WITH SAND, MAY, 1913.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 70.4 | 57.6 | 51.0 | 69.8 | 56.6 | 50.6 | 64.6 | 50.7 | 48.0 | 62.5 | 50.8 | 48.7 | 55.0 | 48.7 | 47.6 |
| 1 Min.... | 51.6 | 52.5 | 50.1 | 50.9 | 52.0 | 49.8 | 50.7 | 50.0 | 47.7 | 50.8 | 49.9 | 48.6 | 51.8 | 48.5 | 47 5 |
| 2 Max.... | 73.7 | 60.9 | 53.5 | 72.9 | 59.5 | 52.9 | 68.0 | 53.4 | 49.8 | 65.7 | 53.6 | 51.1 | 58.3 | 50.6 | 48.5 |
| 2 Min.... | 55.9 | 55.9 | 52.8 | 54.8 | 55.2 | 52.2 | 54.7 | 52.8 | 49.2 | 55.0 | 52.9 | 50.6 | 55.1 | 49.8 | 48 0 |
| 3 Max.... | 72.0 | 62.5 | 55.7 | 71.0 | 61.4 | 54.9 | 67.9 | 56.0 | 51.6 | 66.6 | 56.2 | 53.4 | 60.6 | 52.6 | 49.7 |
| 3 Min.... | 59.5 | 59.0 | 55.0 | 58.2 | 57.9 | 54.3 | 58.5 | 55.4 | 51.1 | 58.4 | 55.5 | 53.0 | 58.0 | 51.8 | 49.4 |
| 5 Max.... | 70.9 | 63.3 | 58.3 | 70.0 | 62.1 | 57.4 | 68.0 | 58.9 | 54.5 | 66.8 | 59.1 | 56.4 | 62.7 | 56.0 | 52.7 |
| 5 Min.... | 64.4 | 62.0 | 58.0 | 63.6 | 60.9 | 57.1 | 62.8 | 58.7 | 54.2 | 63.1 | 58.9 | 56.0 | 61.5 | 55.4 | 52.0 |
| 6 Max.... | 68.0 | 62.1 | 58.4 | 69.0 | 61.7 | 57.5 | 67.2 | 59.5 | 55.4 | 65.4 | 59.5 | 57.0 | 63.6 | 57.2 | 53.8 |
| 6 Min.... | 59.6 | 59.9 | 57.8 | 58.5 | 58.9 | 56.9 | 60.6 | 59.0 | 55.1 | 60.9 | 59.0 | 56.7 | 61.4 | 56.9 | 53.5 |
| 7 Max.... | 68.9 | 60.0 | 57.4 | 69.2 | 59.2 | 56.9 | 66.4 | 58.6 | 55.7 | 63.5 | 58.3 | 57.0 | 61.1 | 57.9 | 54.8 |
| 7 Min.... | 50.7 | 56.0 | 56.0 | 49.3 | 55.4 | 55.5 | 52.6 | 57.2 | 55.1 | 53.5 | 56.8 | 55.8 | 58.1 | 57.4 | 54.7 |
| 8 Max.... | 66.2 | 58.7 | 56.7 | 66.0 | 58.1 | 56.2 | 63.6 | 57.6 | 55.0 | 61.8 | 57.1 | 55.9 | 59.0 | 57.4 | 55.1 |
| 8 Min.... | 53.0 | 55.8 | 55.6 | 51.8 | 55.2 | 55.1 | 53.6 | 56 4 | 54.6 | 53.6 | 55.8 | 55.0 | 57.1 | 56.9 | 55.0 |
| 10 Max.... | 64.0 | 57.1 | 55.5 | 64.0 | 56.5 | 55.4 | 60.4 | 56.0 | 55.0 | 58.3 | 55.0 | 55.5 | 55.7 | 57.1 | 55.8 |
| 10 Min.... | 48.0 | 53.1 | 53.6 | 46.4 | 52.5 | 53.7 | 49.2 | 54.3 | 53.9 | 48.9 | 53.3 | 53.9 | 53.5 | 55.7 | 55.2 |
| 12 Max.... | 61.4 | 57.2 | 55.9 | 60.7 | 56.5 | 55.1 | 59.4 | 56.3 | 54.1 | 58.0 | 55.2 | 54.4 | 55.4 | 54.7 | 54.3 |
| 12 Min.... | 52.0 | 54.9 | 54.5 | 51.2 | 54.3 | 54.0 | 53.1 | 55.0 | 53.7 | 52.0 | 54.1 | 53.8 | 53.7 | 54.3 | 54.0 |
| 13 Max.... | 65.5 | 60.1 | 56.9 | 64.8 | 59.5 | 55.2 | 64.2 | 58.5 | 53.9 | 62.6 | 56.3 | 54.1 | 58.3 | 54.3 | 53.9 |
| 13 Min.... | 53.4 | 55.0 | 54.8 | 52.5 | 54.5 | 54.0 | 54.1 | 55.2 | 53.6 | 53.7 | 54.4 | 54.0 | 54.2 | 54.0 | 53.6 |
| 14 Max.... | 60.5 | 57.7 | 56.4 | 62.2 | 58.0 | 55.5 | 59.7 | 57.1 | 54.4 | 59.1 | 56.6 | 55.0 | 58.0 | 54.9 | 53.8 |
| 14 Min.... | 54.9 | 55.9 | 55.6 | 54.0 | 55.4 | 54.9 | 56.3 | 56.4 | 54.2 | 55.9 | 55.9 | 54.7 | 56 1 | 54.7 | 53.7 |
| 15 Max.... | 63.2 | 59.1 | 56.6 | 64.9 | 59.8 | 55.6 | 62.0 | 56.4 | 54.4 | 62.6 | 56.9 | 55.0 | 59.8 | 55.1 | 54.2 |
| 15 Min.... | 52.8 | 54.4 | 54.6 | 52.3 | 54.1 | 54.2 | 53.7 | 55.0 | 53.9 | 53.4 | 54.9 | 54.5 | 55.9 | 55.0 | 54.0 |
| 16 Max.... | 65.2 | 59.2 | 57.0 | 68.0 | 60.0 | 56.5 | 62.6 | 57.5 | 54.8 | 62.9 | 57.4 | 55.6 | 60.3 | 56.1 | 54.5 |
| 16 Min.... | 55.5 | 56.1 | 56.2 | 55.2 | 56.0 | 55.6 | 56.8 | 56.7 | 54.4 | 56 6 | 56.5 | 55.3 | 57.7 | 55.9 | 54.4 |
| 17 Max.... | 64.7 | 60.1 | 57.8 | 66.2 | 60.6 | 56.9 | 61.8 | 57.4 | 54.9 | 61.9 | 57.6 | 55.9 | 60.8 | 56.6 | 55.0 |
| 17 Min.... | 53.8 | 55.9 | 55.9 | 53.3 | 56 1 | 55.4 | 54.9 | 56.4 | 54.7 | 54.3 | 56.1 | 55.4 | 57.5 | 56 2 | 54.9 |
| 19 Max.... | 70.0 | 62.9 | 58.9 | 70.0 | 62.6 | 57.1 | 67.0 | 57.7 | 55.4 | 64.0 | 57.3 | 55.9 | 61.6 | 56.9 | 55.5 |
| 19 Min.... | 52.5 | 55 5 | 55.8 | 51.1 | 55.3 | 55.4 | 53.1 | 55.7 | 54.8 | 51.4 | 54.8 | 55.1 | 56.3 | 56.2 | 55.4 |
| 20 Max.... | 62.4 | 60.1 | 59.0 | 62.0 | 59.6 | 58.1 | 61.0 | 59.0 | 55.9 | 58.5 | 57.9 | 56.3 | 59.4 | 57.0 | 55.5 |
| 20 Min.... | 58.6 | 59.3 | 58.4 | 57.6 | 58.6 | 57.4 | 58.6 | 58.3 | 55.7 | 56.7 | 57.2 | 56.0 | 58.6 | 56.8 | 55.5 |
| 21 Max.... | 65.5 | 60.8 | 58.3 | 65.8 | 60.7 | 57.0 | 63.6 | 58.0 | 55.9 | 63.2 | 57.6 | 56.0 | 60.2 | 56.8 | 55.7 |
| 21 Min.... | 56.1 | 57.1 | 56.9 | 55.3 | 56.5 | 56.1 | 55.9 | 56.9 | 55.4 | 54.1 | 55.9 | 55.5 | 57 0 | 56.5 | 55.5 |
| 22 Max.... | 59.8 | 59.3 | 58.8 | 58.4 | 59.0 | 58.0 | 59.5 | 59.0 | 56.1 | 58.9 | 58.7 | 56.8 | 60.3 | 57.4 | 55.9 |
| 22 Min.... | 58.1 | 58.3 | 58.0 | 57.8 | 58.0 | 57.1 | 58.5 | 58 4 | 56.0 | 57.9 | 58.0 | 56.7 | 59.6 | 57.0 | 55.7 |
| 23 Max.... | 58.2 | 57.0 | 56.1 | 58.4 | 56.8 | 55.9 | 57.9 | 56.9 | 56.0 | 57.4 | 56.1 | 56.2 | 58.0 | 57.3 | 56.1 |
| 23 Min.... | 53.3 | 55.0 | 55.3 | 52.5 | 54.5 | 55.1 | 54.3 | 56.0 | 55.2 | 53.7 | 55.5 | 55.4 | 56.6 | 56.6 | 56.0 |
| 24 Max.... | 67.1 | 61.6 | 58.0 | 68.1 | 62.0 | 56.6 | 65.2 | 57.2 | 55.0 | 63.4 | 57.5 | 5.53 | 61.5 | 56.6 | 56.0 |
| 24 Min.... | 53.4 | 54.6 | 55.1 | 52.7 | 54.1 | 54.6 | 53 9 | 55.3 | 54.5 | 53.4 | 55.0 | 54.8 | 56.3 | 56.2 | 55.6 |
| 26 Max.... | 53.7 | 53.5 | 55.2 | 53.4 | 53.2 | 55.2 | 53.5 | 56.0 | 55.5 | 53.3 | 54.9 | 55.6 | 55.3 | 57.0 | 55.9 |
| 26 Min.... | 49.7 | 53.0 | 53.8 | 48.5 | 52.4 | 53.8 | 51.2 | 54.2 | 54.4 | 50.1 | 53.5 | 54.5 | 54.1 | 55.9 | 55.5 |
| 27 Max.... | 66.2 | 59.1 | 55.7 | 67.7 | 60.0 | 54.9 | 63.0 | 54.9 | 53.8 | 61.8 | 55.2 | 53.8 | 58.8 | 55.2 | 55.4 |
| 27 Min.... | 50.5 | 52.0 | 53.0 | 49.9 | 51.7 | 53.0 | 51.0 | 53 3 | 53.1 | 50.9 | 52.9 | 53.4 | 53.5 | 54.7 | 54.9 |
| 28 Max.... | 74.1 | 64.1 | 59.2 | 74.4 | 64.4 | 57.4 | 69.5 | 57.7 | 54.2 | 67.7 | 58.2 | 54.8 | 62.5 | 55.5 | 54.9 |
| 28 Min.... | 54.0 | 55.7 | 55.7 | 53.3 | 55.6 | 55.0 | 54.4 | 55.5 | 54.0 | 53.7 | 55.0 | 54.5 | 56.7 | 55.2 | 54.6 |
| 29 Max.... | 68.0 | 63.0 | 60.9 | 68.0 | 62.6 | 59.1 | 64.6 | 60.4 | 56.4 | 63.4 | 60.0 | 57.2 | 62.5 | 57.3 | 55.4 |
| 29 Min.... | 60.7 | 61.2 | 59.7 | 59.7 | 60.6 | 58.4 | 61.0 | 59.4 | 55.9 | 59.5 | 58.7 | 56.9 | 60.7 | 56.8 | 55.0 |
| 30 Max.... | 64.8 | 59.9 | 59.2 | 65.0 | 59.5 | 58.4 | 63.0 | 59.6 | 57.0 | 63.1 | 59.0 | 57.7 | 60.6 | 57.9 | 56.1 |
| 30 Min.... | 56.7 | 58.2 | 58.2 | 55.4 | 57.5 | 57.1 | 58 1 | 58.5 | 56.7 | 57.5 | 58.1 | 57.1 | 59.1 | 57.5 | 55 9 |
| 31 Max.... | 71.9 | 63.5 | 60.0 | 74.5 | 64.1 | 58.5 | 68.2 | 59.5 | 57.0 | 67.7 | 60.0 | 57.5 | 63.8 | 58.0 | 56.6 |
| 31 Min.... | 58.1 | 58.7 | 58.2 | 57.4 | 58.3 | 57.5 | 59.0 | 58.7 | 56.7 | 58.6 | 58 5 | 57.3 | 59.9 | 57.9 | 56.5 |
| Ave. Max. | 66.01 | 60.02 | 57.17 | 66.32 | 59.77 | 56.26 | 63.53 | 57.22 | 54.60 | 62.31 | 57.00 | 55.31 | 59.73 | 56.85 | 54.34 |
| Ave. Min. | 54.88 | 56.35 | 55.72 | 53.97 | 55.83 | 55.12 | 55.41 | 56.10 | 54.15 | 54.91 | 55.68 | 54.79 | 56.92 | 55.38 | 54.08 |
| Ave. Range | 11.13 | 3.67 | 1.45 | 12.35 | 3.94 | 1.14 | 8.12 | 1.12 | 0.45 | 7.40 | 1.34 | 0.52 | 2.81 | 0.47 | 0.26 |

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TABLE 45.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JUNE, 1913.

| Date—Maximum. minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 Max.... | 78.5 | 69.4 | 64.5 | 78.2 | 68.9 | 62.1 | 74.8 | 63.4 | 58.9 | 71.7 | 63.1 | 60.0 | 67.5 | 60.2 | 57.8 |
| 2 Min.... | 59.5 | 62.1 | 61.5 | 58.4 | 61.9 | 60.5 | 60.4 | 61.5 | 58.8 | 58.5 | 60.6 | 59.5 | 62.3 | 60.0 | 57.0 |
| 3 Max.... | 78.1 | 70.9 | 66.3 | 77.5 | 69.9 | 63.5 | 75.8 | 65.5 | 60.4 | 73.5 | 65.1 | 61.0 | 68.8 | 61.3 | 58.7 |
| 3 Min.... | 64.1 | 64.8 | 63.7 | 63.2 | 64.0 | 62.1 | 64.2 | 63.7 | 60.1 | 62.2 | 62.6 | 61.0 | 64.5 | 61.1 | 58.4 |
| 4 Max.... | 77.9 | 70.2 | 66.0 | 77.0 | 69.0 | 63.5 | 75.8 | 65.5 | 61.6 | 73.0 | 64.9 | 62.4 | 68.4 | 62.4 | 60.5 |
| 4 Min.... | 61.3 | 64.2 | 63.7 | 59.8 | 63.6 | 62.2 | 62.5 | 64.0 | 61.4 | 60.2 | 62.6 | 61.6 | 63.9 | 62.0 | 60.4 |
| 5 Max.... | 78.2 | 70.4 | 66.2 | 77.0 | 69.1 | 63.7 | 76.1 | 66.0 | 62.2 | 73.6 | 65.3 | 62.7 | 68.3 | 62.8 | 61.3 |
| 5 Min.... | 62.2 | 64.5 | 64.0 | 60.9 | 63.7 | 62.5 | 63.4 | 64.5 | 61.9 | 61.2 | 63.1 | 62.1 | 64.4 | 62.4 | 61.1 |
| 6 Max.... | 80.8 | 72.9 | 68.3 | 79.5 | 71.6 | 65.4 | 78.6 | 68.0 | 62.7 | 77.1 | 67.7 | 63.3 | 70.7 | 63.4 | 61.9 |
| 6 Min.... | 66.8 | 66.7 | 65.7 | 66.2 | 66.0 | 63.9 | 67.0 | 66.0 | 62.6 | 65.1 | 65.1 | 63.0 | 66.5 | 63.2 | 61.5 |
| 7 Max.... | 65.0 | 67.3 | 67.5 | 64.5 | 66.3 | 66.0 | 66.6 | 68.5 | 63.9 | 65.1 | 67.5 | 64.9 | 68.0 | 64.5 | 62.6 |
| 7 Min.... | 63.4 | 64.9 | 64.6 | 61.5 | 63.8 | 63.5 | 65.0 | 65.7 | 63.5 | 64.4 | 64.9 | 64.0 | 66.0 | 64.2 | 62.3 |
| 9 Max.... | 70.6 | 64.3 | 61.4 | 70.5 | 63.8 | 59.8 | 68.9 | 61.5 | 60.7 | 67.5 | 60.8 | 61.6 | 63.1 | 62.2 | 62.1 |
| 9 Min.... | 53.0 | 57.9 | 58.7 | 50.9 | 57.0 | 58.4 | 55.1 | 59.9 | 59.5 | 53.2 | 54.4 | 59.1 | 58.7 | 61.0 | 61.0 |
| 10 Max.... | 75.5 | 66.9 | 62.8 | 74.9 | 66.3 | 60.8 | 73.0 | 62.5 | 60.0 | 71.6 | 62.2 | 60.0 | 64.9 | 61.2 | 60.9 |
| 10 Min.... | 54.8 | 58.9 | 59.5 | 52.9 | 58.1 | 58.8 | 56.6 | 60.1 | 59.3 | 54.5 | 58.6 | 59.3 | 59.4 | 60.4 | 60.1 |
| 11 Max.... | 77.7 | 69.0 | 64.7 | 76.6 | 67.9 | 62.4 | 74.9 | 64.0 | 60.5 | 73.7 | 64.0 | 60.9 | 66.2 | 61.2 | 60.0 |
| 11 Min.... | 58.9 | 62.0 | 61.8 | 57.3 | 61.3 | 60.8 | 60.2 | 62.2 | 60.2 | 58.2 | 61.0 | 60.6 | 61.7 | 60.8 | 59.8 |
| 12 Max.... | 79.0 | 70.5 | 66.1 | 77.4 | 69.0 | 63.4 | 76.4 | 65.5 | 61.5 | 75.4 | 65.4 | 62.0 | 67.5 | 61.6 | 60.2 |
| 12 Min.... | 60.8 | 63.5 | 63.2 | 59.0 | 62.7 | 61.9 | 62.0 | 63.5 | 61.4 | 60.0 | 62 5 | 61.7 | 62.7 | 61.5 | 60.1 |
| 13 Max.... | 81.1 | 72.3 | 67.6 | 79.2 | 70.7 | 64.7 | 78.6 | 67.0 | 62.6 | 77.6 | 67.2 | 63.2 | 69.1 | 62.5 | 60.9 |
| 13 Min.... | 63.2 | 65.1 | 64.7 | 62.4 | 64.3 | 63.2 | 64.1 | 65.0 | 62.5 | 62.6 | 64.0 | 62.9 | 64.1 | 62.3 | 60.6 |
| 14 Max.... | 84.9 | 74.6 | 69.2 | 82.8 | 72.7 | 66.0 | 81.6 | 68.9 | 63.6 | 81.1 | 69.1 | 64.5 | 71.2 | 63.5 | 61.5 |
| 14 Min.... | 65.4 | 67.0 | 66.5 | 63.9 | 66.2 | 64.5 | 66.5 | 66.7 | 63.5 | 64.8 | 66.0 | 64.2 | 65.8 | 63.4 | 61.2 |
| 16 Max.... | 90.4 | 80.3 | 74.5 | 86.9 | 77.6 | 70.0 | 87.3 | 73.9 | 67.0 | 86.8 | 74.6 | 68.4 | 76.6 | 67.1 | 64.1 |
| 16 Min.... | 73.1 | 73.0 | 71.3 | 71.1 | 71.7 | 68.6 | 73.6 | 71.6 | 66.8 | 72 4 | 71.2 | 68.1 | 71.3 | 66.7 | 63.5 |
| 17 Max.... | 87.6 | 79.6 | 74.8 | 87.5 | 78.9 | 71.2 | 85.9 | 74.8 | 66.6 | 84.3 | 75.0 | 70.1 | 78.5 | 69.1 | 65.6 |
| 17 Min.... | 72.9 | 73.9 | 72.5 | 70.8 | 72.4 | 69.7 | 74.4 | 73.2 | 68.6 | 73.4 | 72.8 | 69.9 | 73.4 | 68 6 | 65.1 |
| 18 Max.... | 87.4 | 78.7 | 74.2 | 86.6 | 77.7 | 71.2 | 85.4 | 74.5 | 69.5 | 83.7 | 74.1 | 70.7 | 77.9 | 70.2 | 67.0 |
| 18 Min.... | 71.0 | 73.2 | 72.0 | 69.9 | 72.1 | 70.0 | 73.1 | 73.1 | 69.1 | 70.9 | 71.8 | 69.9 | 73.5 | 70.1 | 66.5 |
| 19 Max.... | 83.0 | 77.8 | 74.4 | 81.5 | 76.6 | 71.7 | 82.4 | 75.0 | 70.0 | 80.9 | 74.4 | 70.8 | 77.6 | 71.1 | 67.9 |
| 19 Min.... | 73.2 | 74.0 | 72.9 | 72.2 | 72.9 | 70.6 | 74.7 | 73.9 | 69.6 | 72.5 | 72.4 | 70.4 | 74.3 | 70.9 | 67.6 |
| 20 Max .... | 78.1 | 74.4 | 72.6 | 78.0 | 73.6 | 70.7 | 77.3 | 74.0 | 70.2 | 76.0 | 72.9 | 70.8 | 75.7 | 71.7 | 68.6 |
| 20 Min.... | 70.8 | 72.4 | 71.6 | 69.2 | 71.0 | 69.8 | 72.6 | 73.4 | 69.6 | 71.9 | 71.9 | 70.0 | 73.9 | 71.2 | 68.4 |
| 21 Max.... | 73.1 | 70.9 | 70.5 | 74.1 | 70.1 | 68.6 | 73.2 | 72.0 | 69.4 | 72.7 | 70.9 | 69.7 | 72.6 | 71.3 | 68.8 |
| 21 Min.... | 69.0 | 69.5 | 69.5 | 68.1 | 68.5 | 68.3 | 70.7 | 70 8 | 68 5 | 70.0 | 70.1 | 68.8 | 71.8 | 70.7 | 68.6 |
| 23 Max.... | 85.9 | 76.1 | 71.2 | 85.9 | 75.6 | 69.0 | 82.5 | 71.0 | 67.6 | 80.4 | 70.5 | 67.9 | 75.4 | 69.6 | 67.9 |
| 23 Min.... | 66.6 | 68.8 | 68.5 | 65.7 | 68.2 | 67.6 | 68.0 | 69.4 | 67.0 | 66.2 | 68.0 | 67.2 | 69.9 | 69.1 | 67.6 |
| 24 Max.... | 86.1 | 77.6 | 73.1 | 83.6 | 76.9 | 70.6 | 83.6 | 72.8 | 68.7 | 81.7 | 72.2 | 68.9 | 76.6 | 70.0 | 68.2 |
| 24 Min.... | 71.0 | 71.6 | 70.9 | 69.7 | 70.8 | 69.4 | 71.4 | 71 3 | 68 1 | 69.4 | 69 9 | 68.5 | 71.8 | 69.6 | 67.9 |
| 25 Max.... | 87.0 | 79.4 | 75.2 | 84.5 | 78.4 | 72.4 | 84.9 | 75.0 | 69.6 | 83.5 | 74.6 | 70.1 | 78.2 | 70.9 | 68.8 |
| 25 Min.... | 74.7 | 74.5 | 72.9 | 73.0 | 73.5 | 71.1 | 75.1 | 73.5 | 69.4 | 73.4 | 72.4 | 70.0 | 74.6 | 70.7 | 68.1 |
| 26 Max.... | 88.8 | 80.5 | 76.4 | 84.7 | 79.5 | 73.4 | 86.3 | 76.2 | 71.3 | 85.0 | 75.9 | 71.5 | 79.7 | 72.1 | 69.0 |
| 26 Min.... | 76.0 | 75.4 | 74.3 | 74.6 | 74.6 | 72.2 | 76.5 | 74.8 | 70.6 | 74 9 | 74.0 | 71.2 | 75.8 | 72.0 | 68.8 |
| 27 Max.... | 92.1 | 83.8 | 78.8 | 90.0 | 82.2 | 75.2 | 90.1 | 78.4 | 72.0 | 88.4 | 78.4 | 73.0 | 82.0 | 73.6 | 70.2 |
| 27 Min.... | 77.8 | 77.2 | 75.9 | 76.5 | 76.1 | 73.6 | 78.0 | 76.4 | 71 8 | 76.6 | 75.6 | 72.7 | 77.4 | 73.3 | 69.7 |
| 28 Max.... | 95.5 | 85.1 | 80.1 | 92.0 | 83.5 | 76.2 | 93.0 | 80.0 | 73.4 | 91.4 | 79.8 | 74.4 | 83.3 | 74.9 | 71.3 |
| 28 Min.... | 79.6 | 79.0 | 77.7 | 78.2 | 77.9 | 75.0 | 79.9 | 78.1 | 73.3 | 78.2 | 77.3 | 73.1 | 78.7 | 74.6 | 70.8 |
| 30 Max.... | 92.0 | 84.9 | 80.6 | 89.5 | 82.7 | 77.5 | 90.7 | 81.0 | 75.8 | 89.0 | 80.4 | 76.6 | 83.1 | 77.4 | 73.5 |
| 30 Min.... | 79.5 | 80.3 | 76.4 | 77.9 | 78.5 | 76.6 | 80.5 | 79.9 | 75.4 | 78.3 | 78.5 | 76.1 | 79.8 | 77.0 | 73.4 |
| Ave. Max.. | 82.17 | 74.71 | 70.68 | 80.80 | 73.54 | 67.96 | 80.15 | 70.60 | 66.07 | 78.59 | 70.24 | 66.78 | 73.24 | 67.03 | 64.77 |
| Ave. Min.. | 67.54 | 68.98 | 68.16 | 66.13 | 68.03 | 66.59 | 68.62 | 68.89 | 65.70 | 66.92 | 67.65 | 66.20 | 69.05 | 66.67 | 64.38 |
| Ave. Range | 14.63 | 5.73 | 2.52 | 14.67 | 5.51 | 1.37 | 11.53 | 1.71 | 0.37 | 11.67 | 2.59 | 0.58 | 4.19 | 0.36 | 0.39 |

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TABLE 46.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JULY, 1918.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | Max.... | 88.5 | 82.5 | 79.5 | 86.7 | 81.1 | 77.0 | 87.4 | 80.4 | 75.9 | 85.6 | 79.4 | 76.7 | 82.0 | 77.7 | 74.4 |
| | Min.... | 78.2 | 79.1 | 78.1 | 77.0 | 77.7 | 76.1 | 79.8 | 79.5 | 75.4 | 78.1 | 78.3 | 75.9 | 79.9 | 77.4 | 74.0 |
| 2 | Max.... | 91.9 | 84.4 | 80.1 | 89.3 | 82.5 | 76.6 | 90.6 | 80.4 | 75.7 | 88.4 | 79.8 | 76.0 | 82.9 | 77.4 | 74.5 |
| | Min... | 76.3 | 77.8 | 77.0 | 74.9 | 76.8 | 75.4 | 77.6 | 78.3 | 74.9 | 75.4 | 76.9 | 75.2 | 78.3 | 76.9 | 74.1 |
| 3 | Max.... | 94.1 | 84.9 | 80.4 | 90.1 | 82.4 | 77.1 | 91.6 | 80.5 | 75.9 | 90.1 | 80.1 | 76.4 | 82.9 | 77.6 | 74.8 |
| | Min.... | 78.0 | 79.4 | 78.0 | 76 4 | 77.6 | 76.1 | 79.2 | 79.2 | 75.5 | 77.0 | 77.8 | 75.9 | 79.0 | 77.1 | 74 2 |
| 4 | Max.... | 88.6 | 85.0 | 81.8 | 85.6 | 83.0 | 78.4 | 88.7 | 82.2 | 76.5 | 86.9 | 81.6 | 77.1 | 83.9 | 77.9 | 74.7 |
| | Min.... | 81.6 | 81.2 | 79 8 | 80.1 | 80.0 | 77.5 | 82.3 | 80.6 | 76.4 | 80.4 | 79.5 | 76.9 | 80.6 | 77.7 | 74.5 |
| 5 | Max.... | 81.0 | 78.9 | 79.2 | 79.5 | 77.9 | 77.1 | 81.1 | 80.5 | 76.9 | 80.5 | 79.2 | 77.3 | 79.8 | 78.2 | 75.1 |
| | Min.... | 78.1 | 77.9 | 77.7 | 76.5 | 77.0 | 75.9 | 79.2 | 79.0 | 75.9 | 78.4 | 78.2 | 76.3 | 79.0 | 77.7 | 75.0 |
| 7 | Max.... | 82.2 | 74.8 | 72.1 | 81.1 | 74.2 | 71.0 | 79.6 | 73.0 | 72.9 | 77.6 | 71.3 | 72.5 | 74.6 | 75.1 | 74.1 |
| | Min.... | 63.7 | 68.6 | 69.9 | 61.1 | 67.3 | 69.6 | 66.1 | 71.5 | 71.2 | 64.1 | 69.6 | 70.8 | 69.5 | 73.4 | 73.3 |
| 8 | Max.... | 77.7 | 75.1 | 73.1 | 76.7 | 74.5 | 71.6 | 77.6 | 73.4 | 71.2 | 75.5 | 72.3 | 71.1 | 74.8 | 73.1 | 72.4 |
| | Min.... | 67.8 | 70.5 | 70.9 | 65.9 | 69.8 | 70.0 | 68.9 | 71.7 | 70.6 | 66.9 | 69.9 | 70.4 | 70.5 | 72.2 | 71.7 |
| 9 | Max.... | 84.9 | 76.9 | 73.3 | 83.5 | 76.5 | 71.3 | 82.3 | 73.1 | 70.7 | 80.6 | 72.5 | 70.6 | 76.1 | 72.1 | 71.2 |
| | Min.... | 68.9 | 70.5 | 70.4 | 67.5 | 69.8 | 69.9 | 70.0 | 71.4 | 70.1 | 68.6 | 70.1 | 70.1 | 71.2 | 71.7 | 70.9 |
| 10 | Max.... | 85.4 | 77.0 | 73.5 | 80.7 | 76.3 | 71.8 | 83.1 | 73.5 | 71.0 | 81.2 | 72.5 | 71.1 | 75.7 | 72.1 | 70.7 |
| | Min.... | 67.9 | 71.4 | 71.0 | 66.0 | 70.5 | 70.6 | 69.5 | 72.0 | 70.5 | 67.1 | 70.4 | 71.4 | 71.3 | 71.7 | 70 6 |
| 11 | Max.... | 84.7 | 77.2 | 73.9 | 83.2 | 76.1 | 72.0 | 82.8 | 73.9 | 71.1 | 81.0 | 73.0 | 71.6 | 75.4 | 72.0 | 70.5 |
| | Min.... | 68.3 | 71.7 | 71.2 | 66.3 | 70.7 | 70.8 | 70.0 | 72.5 | 70.6 | 67.5 | 70.7 | 70.9 | 71.1 | 71.6 | 70.4 |
| 12 | Max.... | 81.9 | 76.5 | 74.1 | 81.6 | 76.1 | 72.6 | 80.2 | 74.5 | 71.4 | 78.6 | 73.4 | 71.5 | 75.3 | 72.0 | 70.5 |
| | Min.... | 73.1 | 73.7 | 73.0 | 70.8 | 72.9 | 71.9 | 74.3 | 73.9 | 71.2 | 72.5 | 72.4 | 71.4 | 73.1 | 71.9 | 70.4 |
| 14 | Max.... | 87.6 | 79.5 | 75.4 | 85.8 | 78.4 | 73.1 | 84.8 | 75.1 | 71.7 | 83.2 | 74.4 | 72.1 | 76.8 | 72.5 | 70.7 |
| | Min.... | 71.2 | 73 7 | 72.1 | 69.5 | 72.8 | 72.0 | 72.1 | 73.6 | 71.4 | 70.5 | 72.2 | 71.6 | 72.4 | 72.0 | 70.6 |
| 15 | Max.... | 89.1 | 80.0 | 76.1 | 86.0 | 79.1 | 74.1 | 85.8 | 76.0 | 72.3 | 84.4 | 75.4 | 72.9 | 78.4 | 72.9 | 70.9 |
| | Min... | 73.0 | 74.7 | 74.4 | 71.0 | 73.7 | 72.9 | 74.5 | 74.8 | 72.1 | 72.9 | 73.6 | 72.5 | 73.8 | 72.7 | 70.8 |
| 16 | Max.... | 86.0 | 79.9 | 76.7 | 84.0 | 78.8 | 74.8 | 84.5 | 76.8 | 73.0 | 83.1 | 76.0 | 73.6 | 78.2 | 73.8 | 71.5 |
| | Min.... | 74.9 | 75.9 | 75.2 | 72.0 | 75.0 | 74.0 | 75.7 | 75.4 | 72.9 | 73.7 | 74.4 | 73.2 | 75.5 | 73.6 | 71.2 |
| 17 | Max .... | 78.3 | 75.3 | 75.3 | 78.0 | 74.9 | 74.3 | 77.7 | 76.2 | 73.7 | 77.5 | 75.1 | 73.8 | 75.7 | 74.0 | 72.1 |
| | Min.... | 73.0 | 74.1 | 74.3 | 70.5 | 73.1 | 73.4 | 74.2 | 75.1 | 72.9 | 73.8 | 74.3 | 73.1 | 73.6 | 73.6 | 71.9 |
| 18 | Max.... | 85.6 | 78.2 | 75.0 | 87.2 | 79.3 | 73.7 | 82.1 | 74.5 | 72.4 | 80.0 | 74.5 | 72.8 | 78.2 | 73.9 | 72.1 |
| | Min.... | 71.5 | 72.9 | 72.8 | 70.4 | 73.3 | 72.2 | 73.0 | 74.0 | 71.9 | 72.4 | 73.1 | 72.4 | 74.2 | 73.5 | 72.0 |
| 19 | Max.... | 86.1 | 79.1 | 75.8 | 86.0 | 79.0 | 74.1 | 82.8 | 75.0 | 72.3 | 80.9 | 74.5 | 73.0 | 76.9 | 74.1 | 72.1 |
| | Min.... | 71.3 | 73 8 | 73.7 | 70.0 | 73.6 | 73.0 | 72.3 | 74.0 | 72.0 | 71.0 | 72.9 | 72.3 | 73.6 | 73.5 | 72.0 |
| 21 | Max.... | 86.4 | 78.5 | 74.8 | 84.9 | 77.6 | 73.0 | 83.3 | 74.4 | 72.4 | 81.2 | 73.5 | 72.5 | 77.0 | 73.2 | 71.7 |
| | Min.... | 68.5 | 72.1 | 72.4 | 66.6 | 71 3 | 71.7 | 69.9 | 73.0 | 71.5 | 68.0 | 71.4 | 71.5 | 71.4 | 72.3 | 71.6 |
| 22 | Max.... | 84.0 | 77.5 | 74.6 | 82.8 | 75.7 | 73.1 | 81.4 | 74.5 | 72.4 | 79.7 | 73.0 | 72.5 | 75.5 | 73.0 | 71.5 |
| | Min.... | 68.8 | 72.4 | 72.6 | 66.5 | 71.2 | 71.7 | 70.0 | 73.0 | 71.6 | 67.7 | 71.1 | 71.3 | 71.0 | 72.1 | 71.2 |
| 23 | Max.... | 71.9 | 73.6 | 74.1 | 70.5 | 72.4 | 73.0 | 72.3 | 74.4 | 71.9 | 70.5 | 72.8 | 72.0 | 72.5 | 72.5 | 71.1 |
| | Min.... | 70.8 | 71.7 | 72.1 | 69.2 | 71.0 | 71.4 | 71.5 | 72.6 | 71.4 | 70.1 | 71.1 | 71.1 | 71.5 | 71.9 | 71.0 |
| 24 | Max.... | 77.6 | 73.5 | 71.3 | 77.0 | 73.3 | 70.0 | 77.0 | 71.1 | 70.6 | 75.4 | 70.5 | 70.4 | 73.4 | 71.3 | 70.8 |
| | Min.... | 65.5 | 68.1 | 69.1 | 63.9 | 67.0 | 68.8 | 66.6 | 69.9 | 69.5 | 65.7 | 68.6 | 69.4 | 68.7 | 70.5 | 70.4 |
| 25 | Max.... | 82.0 | 74.5 | 71.3 | 81.2 | 72.5 | 69.9 | 79.7 | 71.0 | 69.8 | 78.1 | 70.5 | 69.8 | 73.8 | 70.8 | 70.1 |
| | Min.... | 64.0 | 68.1 | 68.8 | 61.9 | 67.8 | 68.6 | 65.7 | 69.5 | 69.0 | 64.0 | 68.1 | 69.0 | 68.5 | 70.0 | 69.9 |
| 26 | Max.... | 87.0 | 78.0 | 74.0 | 85.0 | 75.6 | 71.6 | 83.9 | 73.1 | 69.8 | 82.6 | 72.9 | 70.0 | 76.5 | 70.6 | 69.6 |
| | Min.... | 70.4 | 71.6 | 71.6 | 68.5 | 70.1 | 70.5 | 70.9 | 71.5 | 69.7 | 69.3 | 70.5 | 69.7 | 71.2 | 70.5 | 69.5 |
| 28 | Max.... | 86.8 | 79.6 | 76.1 | 87.5 | 80.0 | 74.1 | 84.1 | 75.9 | 72.1 | 82.8 | 75.8 | 73.0 | 80.4 | 73.1 | 70.8 |
| | Min.... | 73.0 | 74.5 | 74.3 | 69.1 | 73.4 | 72.8 | 74.3 | 74.6 | 72.0 | 73.5 | 74.0 | 72.6 | 74.9 | 72.9 | 70.5 |
| 29 | Max.... | 89.9 | 80.6 | 76.9 | 89.1 | 80.4 | 74.8 | 85.6 | 76.5 | 73.0 | 84.5 | 76.2 | 73.8 | 80.5 | 74.4 | 71.8 |
| | Min.... | 74.5 | 75.8 | 75.2 | 72.7 | 75.2 | 74.0 | 75.6 | 75.6 | 72.7 | 74.6 | 74.8 | 73.4 | 76.7 | 74.2 | 71 5 |
| 30 | Max.... | 93.9 | 84.0 | 79.4 | 92.0 | 83.4 | 76.7 | 89.9 | 78.5 | 73.9 | 88.9 | 78.6 | 74.6 | 83.5 | 75.5 | 72.9 |
| | Min.... | 76.6 | 78.0 | 77.1 | 74.3 | 77.0 | 75.2 | 77.5 | 77.1 | 73.9 | 75.9 | 76.1 | 74.5 | 78.1 | 75.4 | 72.4 |
| 31 | Max.... | 86.0 | 81.9 | 79.6 | 83.5 | 81.1 | 77.6 | 84.4 | 79.5 | 75.1 | 83.0 | 78.6 | 76.2 | 81.2 | 76.9 | 73.8 |
| | Min.... | 77.2 | 79.4 | 78.3 | 74.2 | 78.1 | 76.4 | 78 2 | 78 4 | 75.0 | 76.5 | 77.4 | 75.8 | 78.9 | 76.6 | 73.5 |
| Ave. | Max.. | 85.15 | 78.77 | 75.83 | 83.65 | 77.85 | 73.87 | 83.12 | 75.85 | 72.80 | 81.55 | 75.08 | 73.14 | 77.85 | 73.98 | 72.08 |
| | Min.. | 72.08 | 74.02 | 73.74 | 70.10 | 73.06 | 72.68 | 73.29 | 74.51 | 72.29 | 71.69 | 73.24 | 72.50 | 73.98 | 73.50 | 71.82 |
| | Range | 13.07 | 4.75 | 2.09 | 13.55 | 4.79 | 1.19 | 9.83 | 1.34 | 0.51 | 9.86 | 1.85 | 0.64 | 3.87 | 0.49 | 0.27 |

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TABLE 47.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, AUGUST, 1913.

| Date— Maximum, minimum. | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | Max.... | 86.1 | 79.6 | 77.0 | 88.1 | 79.4 | 75.7 | 84.5 | 77.7 | 75.4 | 82.6 | 76.5 | 75.8 | 80.6 | 76.8 | 74.1 |
| | Min.... | 71.5 | 75.4 | 75.3 | 68.9 | 74.3 | 74.1 | 73.9 | 76.3 | 74.4 | 72.5 | 75.1 | 74.5 | 76.5 | 76.0 | 74.0 |
| 2 | Max.... | 89.8 | 80.6 | 76.9 | 89.1 | 80.4 | 74.9 | 86.8 | 77.1 | 74.5 | 85.1 | 76.4 | 74.8 | 81.1 | 76.5 | 74.3 |
| | Min.... | 70.4 | 74.1 | 74.4 | 63.4 | 73.0 | 73.5 | 72.6 | 75.5 | 73.8 | 70.8 | 74.0 | 73.8 | 75 5 | 75.8 | 74.0 |
| 4 | Max.... | 85.0 | 77.7 | 74.8 | 84.3 | 77.5 | 73.5 | 83.0 | 75.4 | 73.8 | 81.4 | 74.1 | 73.9 | 78.1 | 75.5 | 74.C |
| | Min.... | 67.9 | 72.4 | 72.9 | 65.4 | 71.4 | 72.2 | 70.3 | 73.8 | 72.8 | 73.5 | 72.2 | 72.6 | 73.6 | 74.6 | 73.6 |
| 5 | Max.... | 84.0 | 77.1 | 74.1 | 82.5 | 76.4 | 73.4 | 81.6 | 74.8 | 73.2 | 80.0 | 73.3 | 73.2 | 76.3 | 74.9 | 73.4 |
| | Min.... | 67.2 | 72.0 | 72.4 | 64.8 | 71.0 | 71.6 | 69.4 | 73.3 | 72.1 | 67 3 | 71 4 | 72.0 | 72.1 | 73.9 | 73.1 |
| 6 | Max.... | 78.8 | 75.4 | 74.4 | 77.8 | 74.6 | 73.5 | 77.5 | 75.0 | 72.6 | 76.2 | 73.3 | 72.7 | 74.8 | 74.0 | 72.8 |
| | Min.... | 71.8 | 73.7 | 73.5 | 70.0 | 72 6 | 72.5 | 72.8 | 74.0 | 72.1 | 71.0 | 72.5 | 72.0 | 73.4 | 73.5 | 72.5 |
| 7 | Max.... | 84.8 | 77.6 | 74.3 | 84.1 | 77.0 | 72.6 | 82.5 | 74.3 | 72.1 | 81.4 | 73.8 | 72.1 | 76.8 | 73.5 | 72.3 |
| | Min.... | 69.3 | 71.4 | 72.0 | 67.4 | 71.2 | 71.4 | 70.5 | 72.6 | 71.7 | 69.2 | 71.4 | 71.7 | 72.5 | 73.0 | 72.2 |
| 8 | Max.... | 85.4 | 78.3 | 75.5 | 84.9 | 78.0 | 74.0 | 82.8 | 75.4 | 72.5 | 82.2 | 74.7 | 72.9 | 78.0 | 73.9 | 72.2 |
| | Min.... | 73.6 | 74.3 | 74.1 | 72.4 | 73.8 | 73.3 | 74.8 | 74.5 | 72.3 | 73.4 | 73.5 | 72.5 | 74.8 | 73.7 | 72.1 |
| 9 | Max.... | 81.7 | 76.8 | 75.4 | 82.4 | 77.1 | 75.1 | 80.0 | 76.0 | 73.4 | 79.9 | 74.9 | 73.5 | 77.4 | 75.0 | 73.1 |
| | Min.... | 72.7 | 74.2 | 74.4 | 71.0 | 74.0 | 74.0 | 74.4 | 75.0 | 73.0 | 73.6 | 74.0 | 73.1 | 74.6 | 74.5 | 72.7 |
| 11 | Max.... | 74.9 | 71.0 | 70.8 | 78.0 | 72.5 | 71.3 | 73.2 | 72.1 | 72.4 | 72.3 | 70.8 | 72.0 | 73.1 | 75.1 | 74.6 |
| | Min.... | 63.5 | 68.4 | 69.4 | 61.7 | 67.9 | 69.9 | 66.0 | 70.7 | 71.0 | 65.2 | 69.5 | 70.5 | 70.5 | 73.7 | 73.9 |
| 12 | Max.... | 80.7 | 73.5 | 70.8 | 82.1 | 74.4 | 70.7 | 77.5 | 70.6 | 70.4 | 76.1 | 70.0 | 70.1 | 73.7 | 73.2 | 73.3 |
| | Min.... | 66.7 | 68.6 | 69.4 | 66.2 | 69.1 | 70.0 | 67.7 | 70.0 | 69.5 | 67.0 | 69.0 | 69.5 | 70.2 | 72.3 | 72.4 |
| 13 | Max.... | 86.6 | 77.6 | 73.6 | 86.8 | 78.1 | 72.1 | 82.8 | 72.4 | 70.0 | 81.8 | 72.5 | 70.2 | 76.7 | 72.4 | 71.7 |
| | Min.... | 68.2 | 70.6 | 70.9 | 66.9 | 70.5 | 70.6 | 69.0 | 70.7 | 69.6 | 68.0 | 70.0 | 69.9 | 70.9 | 71.8 | 71.4 |
| 14 | Max.... | 87.6 | 79.7 | 76.0 | 87.6 | 79.5 | 74.0 | 84.5 | 74.8 | 71.1 | 83.6 | 74.8 | 71.7 | 79.0 | 72.6 | 71.1 |
| | Min.... | 73.5 | 74.5 | 73.9 | 72.4 | 74.2 | 73.0 | 73.8 | 73.5 | 70.9 | 72.5 | 72.9 | 71.6 | 74.0 | 72.5 | 71.1 |
| 15 | Max.... | 90.7 | 81.4 | 77.5 | 89.9 | 81.2 | 75.3 | 87.0 | 76.6 | 72.5 | 86.2 | 76.8 | 73.5 | 81.5 | 74.0 | 71.8 |
| | Min.... | 75.7 | 76.3 | 75.5 | 74.2 | 75.6 | 74.3 | 76 4 | 75.4 | 72.5 | 75.3 | 74.9 | 73.4 | 76.5 | 73.9 | 71.5 |
| 16 | Max.... | 88.5 | 84.5 | 80.1 | 85.9 | 83.9 | 77.5 | 89.3 | 80.3 | 74.8 | 87.5 | 79.5 | 75.0 | 85.9 | 75.7 | 72.9 |
| | Min.... | 77.5 | 78.2 | 77.4 | 75.8 | 77.5 | 75.6 | 77.8 | 77.1 | 73.8 | 76.8 | 76.6 | 74.8 | 78.4 | 75.5 | 72.5 |
| 18 | Max.... | 82.4 | 78.8 | 76.5 | 84.3 | 79.4 | 75.0 | 82.4 | 76.9 | 74.9 | 82.0 | 76.6 | 74.9 | 81.0 | 77.2 | 75.4 |
| | Min.... | 73.0 | 74.6 | 74 9 | 71.2 | 73.8 | 74.0 | 74.5 | 75.8 | 74.0 | 73.9 | 75.0 | 74.2 | 76.6 | 76.6 | 75.1 |
| 19 | Max.... | 84.1 | 78.1 | 75.5 | 85.9 | 79.1 | 74.9 | 82.1 | 76.4 | 74.3 | 80.3 | 75.4 | 74.6 | 79.1 | 77.1 | 75.2 |
| | Min.... | 70.6 | 73.7 | 73.9 | 69.2 | 73.9 | 73.8 | 73.1 | 75.0 | 73.4 | 72.0 | 74.1 | 73.7 | 76.1 | 76.1 | 74.9 |
| 20 | Max.... | 84.4 | 77.6 | 74.9 | 85.0 | 78.0 | 74.5 | 81.7 | 75.4 | 73.7 | 80.5 | 74.0 | 73.9 | 78.5 | 76.1 | 74.7 |
| | Min.... | 68.6 | 72.8 | 73.1 | 66.7 | 72.5 | 73.1 | 70.4 | 73.9 | 72.8 | 68.9 | 72.4 | 72.7 | 73.5 | 75.0 | 74.3 |
| 21 | Max.... | 78.8 | 75.6 | 75.0 | 78.8 | 75.4 | 74.5 | 78.0 | 75.4 | 73.3 | 77.5 | 74.3 | 73.5 | 76.5 | 75.4 | 74.0 |
| | Min.... | 73.8 | 74.2 | 74.4 | 72.1 | 74.0 | 73.6 | 74.1 | 74.5 | 72.9 | 72.9 | 73.6 | 72.9 | 75.1 | 74.7 | 73.6 |
| 22 | Max.... | 76.2 | 74.5 | 73.9 | 78.0 | 75.3 | 73.4 | 76.4 | 74.5 | 72.6 | 75.7 | 73.8 | 73.0 | 76.2 | 74.7 | 73.4 |
| | Min.... | 71.4 | 73.0 | 73.1 | 69.8 | 72.8 | 72.7 | 72.9 | 73.7 | 72.1 | 72.3 | 73.1 | 72.4 | 74.9 | 74.3 | 73.3 |
| 23 | Max.... | 78.5 | 74.1 | 72.0 | 79.0 | 74.9 | 71.7 | 77.0 | 72.1 | 71.9 | 75.9 | 71.5 | 72.0 | 74.0 | 74.0 | 73.3 |
| | Min.... | 65.9 | 69.3 | 70.1 | 64.9 | 69.4 | 70.7 | 67.7 | 71.1 | 70.8 | 67.0 | 70.1 | 70.9 | 70.6 | 72.8 | 72.7 |
| 25 | Max.... | 74.9 | 71.4 | 70.5 | 74.6 | 71.4 | 70.7 | 73.3 | 70.9 | 70.4 | 72.4 | 69.8 | 70.5 | 70.6 | 71.4 | 71 2 |
| | Min.... | 63.6 | 68.5 | 69.3 | 61.5 | 67.9 | 69.2 | 65.4 | 69.5 | 69.4 | 64.0 | 68.3 | 69.3 | 67.5 | 70.4 | 70.7 |
| 26 | Max.... | 82.9 | 75.5 | 72.2 | 82.6 | 75.6 | 71.0 | 79.8 | 71.3 | 69.3 | 79.0 | 71.3 | 69.5 | 74.8 | 70.2 | 70.3 |
| | Min.... | 68.1 | 69.5 | 69.9 | 67.1 | 69.4 | 69.6 | 68.5 | 69.8 | 69.0 | 67.6 | 69.0 | 69.2 | 69.3 | 69.9 | 69.8 |
| 27 | Max.... | 83.1 | 75.7 | 72.6 | 82.7 | 75.4 | 71.3 | 80.3 | 71.8 | 70.0 | 79.4 | 71.5 | 70.4 | 75.1 | 70.7 | 69.8 |
| | Min.... | 67.2 | 70.6 | 70.6 | 65.5 | 69 9 | 70.2 | 68.0 | 70.5 | 69.4 | 67.0 | 69.7 | 69.9 | 69.9 | 70.2 | 69.5 |
| 28 | Max.... | 73.4 | 71.5 | 72.0 | 73.0 | 71.0 | 71.5 | 72.6 | 72.0 | 70.2 | 71.7 | 71.1 | 70.5 | 71.5 | 70.8 | 69.9 |
| | Min.... | 69.0 | 70.2 | 71.0 | 67.5 | 69.6 | 70.1 | 69.5 | 70.8 | 69.8 | 68.7 | 70 0 | 69.9 | 70.3 | 70.4 | 69.6 |
| 29 | Max.... | 75.1 | 71.0 | 69.5 | 74.1 | 70.6 | 69.3 | 73.4 | 69.9 | 69.5 | 72.5 | 68.8 | 69.6 | 71.0 | 70.2 | 69.8 |
| | Min.... | 63.5 | 67.5 | 68.2 | 62.0 | 67.0 | 68.4 | 65.0 | 68.6 | 68.6 | 64.1 | 67.5 | 68.5 | 68.0 | 69.6 | 69 5 |
| 30 | Max.... | 76.4 | 72.1 | 70.1 | 75.6 | 72.0 | 69.1 | 75.0 | 69.5 | 68.8 | 74.0 | 69.2 | 68.9 | 71.6 | 69.7 | 69.5 |
| | Min.... | 64.1 | 67.5 | 68.0 | 62.6 | 67.2 | 68 1 | 65.3 | 68.1 | 68.0 | 64.3 | 67.3 | 68.1 | 68.0 | 69.0 | 69.0 |
| Ave. | Max.. | 82.05 | 76.41 | 74.07 | 82.16 | 76.46 | 73.08 | 80.20 | 74.18 | 72.22 | 79.12 | 73.41 | 72.41 | 76.65 | 73.87 | 72.62 |
| | Min.. | 69.55 | 72.13 | 72.38 | 67.72 | 71.67 | 71.90 | 70.92 | 72.83 | 71.53 | 69.95 | 71.81 | 71.68 | 72.82 | 73.22 | 72.27 |
| | Range | 12.50 | 4.28 | 1.69 | 14.44 | 4.79 | 1.18 | 9.28 | 1.35 | 0.69 | 9.17 | 1.60 | 0.73 | 3.83 | 0.65 | 0.35 |

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TABLE 48.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, SEPTEMBER, 1913.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | Max.... | 78.2 | 71.8 | 70.2 | 78.0 | 71.5 | 69.6 | 75.1 | 70.0 | 68.4 | 74.8 | 69.5 | 68.8 | 71.0 | 69.3 | 68.7 |
| | Min.... | 68.8 | 69.5 | 69.5 | 67.8 | 69.2 | 69.1 | 69.1 | 69.5 | 68.3 | 68.5 | 69.0 | 68.5 | 69.3 | 69.2 | 68.2 |
| 2 | Max.... | 85.7 | 76.9 | 72.8 | 85.0 | 76.4 | 70.9 | 82.1 | 71.6 | 68.7 | 81.9 | 71.8 | 69.3 | 76.2 | 69.8 | 69.0 |
| | Min.... | 68.5 | 70.0 | 70.1 | 67.5 | 69.5 | 69.4 | 68.9 | 69.9 | 68.6 | 67.9 | 69.2 | 69.0 | 69.5 | 69.6 | 68.8 |
| 3 | Max.... | 84.0 | 78.1 | 75.0 | 83.1 | 77.5 | 72.8 | 82.0 | 74.0 | 70.2 | 81.5 | 74.1 | 71.1 | 78.1 | 71.2 | 69.5 |
| | Min.... | 73.2 | 74.0 | 73.1 | 71.7 | 73.4 | 72.0 | 73.4 | 73.5 | 69.9 | 72.5 | 71.9 | 70.9 | 73.9 | 71.1 | 68.8 |
| 4 | Max.... | 77.6 | 74.6 | 74.3 | 76.9 | 74.0 | 73.1 | 76.6 | 74.1 | 71.1 | 75.9 | 73.5 | 72.0 | 75.3 | 72.4 | 70.4 |
| | Min.... | 72.0 | 73.0 | 73.0 | 71.3 | 72.5 | 72.1 | 72.8 | 73.2 | 70.9 | 71.6 | 72.1 | 71.5 | 73.6 | 72.0 | 70 0 |
| 5 | Max.... | 83.0 | 75.7 | 72.6 | 82.0 | 74.9 | 71.1 | 80.4 | 72.4 | 71.0 | 79.7 | 72.0 | 71.2 | 76.1 | 72.2 | 70.7 |
| | Min.... | 68.0 | 70.4 | 70.7 | 67.0 | 70.0 | 70.2 | 68.8 | 71.0 | 70.1 | 68.0 | 70.1 | 70.5 | 71.4 | 71.5 | 70.5 |
| 6 | Max.... | 83.5 | 77.5 | 73.9 | 82.4 | 76.2 | 71.6 | 81.7 | 73.4 | 70.6 | 80.7 | 73.0 | 71.1 | 77.3 | 72.0 | 70.7 |
| | Min.... | 67.4 | 71.0 | 71.0 | 66.4 | 70.3 | 70.5 | 68 8 | 71.4 | 70.1 | 67.5 | 69.7 | 70.5 | 71 4 | 71.5 | 70.1 |
| 8 | Max.... | 75.6 | 73.6 | 73.6 | 75.6 | 73.4 | 72.4 | 75.6 | 74.0 | 71.6 | 74.8 | 72.4 | 72.0 | 74.9 | 72.9 | 71.1 |
| | Min.... | 70.5 | 72.1 | 72.5 | 69 0 | 71.3 | 71.6 | 72.1 | 72.9 | 71.1 | 71.5 | 72 0 | 71.5 | 73.4 | 72.5 | 71 0 |
| 9 | Max.... | 75.9 | 71.1 | 69.7 | 76.1 | 71.0 | 69.7 | 74.2 | 70.7 | 70.8 | 73.1 | 69.3 | 70.9 | 72.0 | 72.3 | 71.2 |
| | Min.... | 61.5 | 67.0 | 68.4 | 59.0 | 66.1 | 68.2 | 63.9 | 69.1 | 69.5 | 62.9 | 67.1 | 69.2 | 67.9 | 70.9 | 70.8 |
| 10 | Max.... | 75.6 | 70.0 | 68.1 | 75.5 | 69.6 | 68.5 | 73.4 | 68.9 | 69.3 | 72.3 | 67.5 | 69.1 | 70.5 | 70.7 | 70.2 |
| | Min.... | 60.0 | 65.5 | 66.7 | 58.1 | 64.7 | 67.0 | 62.0 | 67.3 | 67.9 | 60.8 | 65.0 | 67.6 | 66.0 | 69.3 | 70 0 |
| 11 | Max.... | 76.6 | 70.5 | 68.4 | 76.4 | 70.1 | 67.9 | 74.0 | 67.9 | 68.0 | 73.1 | 66.8 | 68.0 | 70.4 | 69.3 | 69.5 |
| | Min.... | 61.5 | 65.8 | 66.5 | 59.9 | 65.4 | 66.7 | 62.9 | 66.8 | 67.1 | 61 5 | 65.1 | 66.9 | 66.0 | 68.4 | 68.9 |
| 12 | Max.... | 74.8 | 70.9 | 69.0 | 74.2 | 70.4 | 68.6 | 73.5 | 68.8 | 67.6 | 72.3 | 67.8 | 67.9 | 70.9 | 68.8 | 68.3 |
| | Min.... | 64.5 | 67.2 | 67.7 | 63 6 | 66.8 | 67.7 | 65.6 | 67.7 | 67.2 | 64.6 | 66.5 | 67.3 | 67.8 | 68.3 | 68.0 |
| 13 | Max.... | 70.6 | 68.5 | 67.4 | 70.2 | 68.1 | 67.6 | 70.3 | 67.5 | 67.5 | 69.0 | 66.4 | 67.5 | 68.5 | 68.5 | 68.1 |
| | Min.... | 59.3 | 64.6 | 65.9 | 58 6 | 64.1 | 66.4 | 61.5 | 66.1 | 66.5 | 59.9 | 64.7 | 66.4 | 65.1 | 67.4 | 67 9 |
| 15 | Max.... | 70.0 | 65.9 | 64.6 | 69.1 | 65.2 | 65.2 | 68.1 | 64.9 | 65.5 | 67.4 | 63.5 | 65.3 | 65.1 | 66.2 | 66.5 |
| | Min.... | 56 8 | 62.0 | 63 2 | 56.0 | 61.7 | 64.0 | 58.6 | 63.5 | 64.4 | 57.2 | 61.9 | 64.1 | 61.9 | 65.1 | 66.4 |
| 16 | Max.... | 64.4 | 64.6 | 65.3 | 64.1 | 64.5 | 65.2 | 64.0 | 65.0 | 64.6 | 63.9 | 64.1 | 64.6 | 64.5 | 65.3 | 65.5 |
| | Min.... | 63.0 | 64.0 | 64.5 | 62.6 | 63.7 | 64.7 | 63.1 | 64.4 | 64.5 | 62.8 | 63.6 | 64.5 | 64.0 | 65.1 | 65.4 |
| 17 | Max.... | 67.0 | 65.2 | 65.1 | 67.1 | 65.2 | 65.0 | 65.6 | 64.9 | 64.3 | 66.0 | 64.5 | 64.4 | 65.6 | 64.9 | 65.1 |
| | Min.... | 64.2 | 64.2 | 64.5 | 64.0 | 64.1 | 64.6 | 64.1 | 64 5 | 64.1 | 64.2 | 63.9 | 64.4 | 64.6 | 64.7 | 64.5 |
| 18 | Max.... | 63.2 | 63.5 | 63.6 | 63.0 | 63.5 | 64.1 | 63.6 | 64.0 | 64.4 | 63.5 | 63.2 | 64.6 | 63.9 | 65.0 | 64.8 |
| | Min.... | 59.4 | 62.0 | 63.0 | 58.5 | 61.7 | 63.5 | 60.6 | 63.3 | 63.7 | 60.6 | 62.6 | 63.8 | 62.5 | 64.2 | 64.6 |
| 19 | Max.... | 66.3 | 63.7 | 62.6 | 66.7 | 63.9 | 62.6 | 65.4 | 62.4 | 63.5 | 65.1 | 62.0 | 63.5 | 63.8 | 64.1 | 64.5 |
| | Min.... | 57.6 | 59.6 | 61.0 | 55 0 | 59.3 | 61.5 | 58.2 | 61.4 | 62.5 | 59.2 | 60.5 | 62.4 | 59.3 | 63.0 | 63.8 |
| 20 | Max.... | 64.9 | 63.0 | 62.9 | 65.3 | 63.1 | 62.9 | 63.0 | 62.7 | 62.7 | 63.2 | 62.2 | 63.0 | 63.3 | 63.5 | 63.8 |
| | Min.... | 59.9 | 61.3 | 62.3 | 59.3 | 61.2 | 62.6 | 60.1 | 62.2 | 62.3 | 60.1 | 61.6 | 62.5 | 61.5 | 63.8 | 63.2 |
| 22 | Max.... | 55.6 | 56.7 | 57.5 | 55.5 | 56.7 | 58.6 | 55.5 | 58.0 | 60.7 | 55.6 | 56.9 | 60.2 | 56.5 | 61.3 | 63.0 |
| | Min.... | 50.7 | 54.8 | 56.7 | 49.6 | 54.5 | 57.9 | 51.8 | 57.1 | 59.5 | 51.8 | 56.1 | 59.0 | 55.0 | 60.1 | 62 5 |
| 23 | Max.... | 58.9 | 57.6 | 56.9 | 59.2 | 58.2 | 57.4 | 58.1 | 56.2 | 58.7 | 58.1 | 55.9 | 58.2 | 56.6 | 59.4 | 61.9 |
| | Min.... | 47.9 | 52.5 | 54.7 | 47.4 | 52.0 | 56.0 | 48.9 | 54.9 | 57.7 | 48.4 | 54.0 | 57.2 | 52.3 | 58.0 | 61.0 |
| 24 | Max.... | 67.6 | 62.0 | 59.5 | 69.5 | 63.0 | 59.5 | 64.7 | 58.0 | 57.8 | 65.0 | 58.5 | 57.7 | 59.9 | 58.0 | 60.2 |
| | Min.... | 53.0 | 55.5 | 56 6 | 52 6 | 56.0 | 57 7 | 53.4 | 56.1 | 57.5 | 53.5 | 55.7 | 57.5 | 54.9 | 57.5 | 59.6 |
| 25 | Max.... | 70.4 | 64.8 | 62.1 | 71.1 | 65.1 | 61.6 | 67.0 | 60.4 | 58.9 | 67.2 | 60.9 | 59.5 | 62.4 | 58.7 | 59.6 |
| | Min.... | 56.4 | 59.5 | 59.9 | 55.5 | 59.7 | 60.3 | 57.1 | 58.8 | 58.9 | 57.0 | 58.5 | 59.4 | 57.8 | 58.4 | 59.5 |
| 26 | Max.... | 61.6 | 63.0 | 63.1 | 60.7 | 62.9 | 63.0 | 61.4 | 62.0 | 60.6 | 61.4 | 61.9 | 61.4 | 61.5 | 59.9 | 59.9 |
| | Min.... | 60.1 | 61.5 | 62.0 | 59.4 | 61.4 | 61 9 | 59.9 | 61.2 | 60.2 | 59.8 | 60.7 | 61.2 | 60.3 | 59.5 | 59.7 |
| 27 | Max.... | 65.2 | 61.1 | 59.5 | 66.1 | 61.5 | 59.9 | 63.1 | 59.0 | 60.6 | 62.7 | 58.2 | 60.7 | 59.6 | 59.9 | 60.5 |
| | Min.... | 50.3 | 56.1 | 57.6 | 49.0 | 55.5 | 58.5 | 51.7 | 57.5 | 59.3 | 51.5 | 56.6 | 59.2 | 55.0 | 58.9 | 60.1 |
| 29 | Max.... | 64.2 | 62.0 | 61.2 | 64.4 | 62.1 | 61.1 | 63.0 | 60.4 | 59.5 | 63.0 | 60.0 | 59.8 | 61.4 | 59.1 | 59.9 |
| | Min.... | 60 2 | 60.5 | 60.5 | 60.0 | 60.5 | 60.6 | 59.6 | 59.8 | 59.3 | 59.5 | 59.4 | 59.5 | 59.3 | 59.0 | 59.8 |
| 30 | Max.... | 68.5 | 64.6 | 62.9 | 69.3 | 64.9 | 62.2 | 66.8 | 62.0 | 60.5 | 66.7 | 61.2 | 60.9 | 64.4 | 60.0 | 60.0 |
| | Min.... | 61.9 | 61.7 | 61 7 | 61 6 | 61.6 | 61.5 | 61.5 | 61 1 | 60 0 | 61.5 | 60.7 | 60 5 | 61.4 | 59.8 | 59 9 |
| Ave. | Max. | 71.11 | 67.57 | 66.22 | 71.02 | 67.42 | 65.85 | 69.55 | 65.89 | 65.27 | 69.15 | 65.27 | 65.49 | 67.30 | 65.95 | 65.87 |
| | Min. | 61.41 | 64.05 | 64.74 | 60.40 | 63.70 | 64.85 | 62.25 | 64.78 | 64.66 | 61.72 | 63.78 | 64.81 | 64.04 | 65.30 | 65.51 |
| | Range | 9.70 | 3.52 | 1.48 | 10.62 | 3.72 | 1.00 | 7.30 | 1.11 | 0.61 | 7.43 | 1.49 | 0.68 | 3.26 | 0.65 | 0.36 |

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TABLE 49.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TPYES OF SOIL, NOT COVERED WITH SAND, OCTOBER, 1913.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 66.4 | 64.1 | 63.1 | 66.2 | 64.1 | 62.7 | 65.6 | 62.6 | 62.6 | 65.8 | 61.9 | 61.9 | 64.2 | 61.3 | 61.0 |
| 1 Min.... | 61.2 | 62.4 | 62.5 | 60.2 | 62.3 | 62.3 | 62.9 | 61.6 | 61.2 | 62.1 | 61.3 | 61.8 | 62.4 | 61.2 | 60.6 |
| 2 Max.... | 58.6 | 61.5 | 62.5 | 57.7 | 61.0 | 62.4 | 59.9 | 62.4 | 61.8 | 59.7 | 61.6 | 62.2 | 61.6 | 61.9 | 61.5 |
| 2 Min.... | 57.1 | 59.5 | 60.8 | 56.1 | 59.1 | 61.2 | 58.0 | 61.0 | 61.4 | 58.1 | 59.8 | 61.6 | 59.9 | 61.5 | 61.4 |
| 3 Max.... | 63.0 | 61.0 | 59.9 | 62.6 | 61.1 | 59.7 | 62.1 | 59.5 | 60.6 | 62.1 | 59.1 | 60.5 | 61.4 | 61.0 | 61.5 |
| 3 Min.... | 54.5 | 57.4 | 58.3 | 53.8 | 56.9 | 59.0 | 55.6 | 58.8 | 59.6 | 55.6 | 58.0 | 59.7 | 57.7 | 60.0 | 61.1 |
| 4 Max.... | 64.6 | 61.3 | 59.6 | 65.6 | 61.6 | 59.4 | 63.0 | 59.0 | 59.8 | 62.6 | 58.1 | 59.9 | 60.4 | 60.4 | 61.2 |
| 4 Min.... | 52.1 | 56.7 | 57.9 | 50.4 | 56.0 | 58.3 | 53.6 | 57.9 | 59.0 | 53.5 | 57.0 | 58.9 | 56.1 | 59.4 | 60.7 |
| 6 Max.... | 69.9 | 64.4 | 62.0 | 70.7 | 64.9 | 61.4 | 67.0 | 61.0 | 59.7 | 67.0 | 59.8 | 60.2 | 63.8 | 59.9 | 60.3 |
| 6 Min.... | 57.1 | 59.6 | 59.9 | 55.9 | 59.2 | 60.0 | 57.6 | 59.6 | 59.4 | 57.6 | 58.9 | 59.8 | 59.0 | 59.6 | 60.0 |
| 7 Max.... | 71.5 | 66.4 | 63.9 | 71.9 | 66.6 | 62.9 | 68.6 | 62.6 | 60.6 | 68.6 | 62.4 | 61.4 | 65.8 | 60.8 | 60.5 |
| 7 Min.... | 60.7 | 62.4 | 62.1 | 59.6 | 62.0 | 61.9 | 61.1 | 61.6 | 60.5 | 61.0 | 60.6 | 61.3 | 61.8 | 60.7 | 60.3 |
| 8 Max.... | 67.6 | 65.7 | 64.6 | 67.5 | 65.6 | 64.0 | 67.1 | 63.9 | 62.0 | 67.2 | 63.8 | 62.7 | 66.0 | 62.1 | 61.4 |
| 8 Min.... | 64.4 | 64.4 | 64.1 | 63.6 | 64.1 | 63.6 | 64.2 | 63.5 | 61.7 | 64.2 | 63.0 | 62.5 | 64.3 | 61.9 | 61.0 |
| 9 Max.... | 69.2 | 66.0 | 64.5 | 69.4 | 66.1 | 63.7 | 68.4 | 63.9 | 62.5 | 68.4 | 63.8 | 63.2 | 66.4 | 62.8 | 62.0 |
| 9 Min.... | 61.5 | 63.0 | 63.3 | 60.2 | 62.6 | 62.9 | 62.5 | 63.3 | 62.3 | 62.3 | 62.4 | 62.9 | 63.2 | 62.6 | 61.9 |
| 10 Max.... | 70.0 | 66.8 | 65.0 | 71.0 | 67.1 | 64.3 | 68.7 | 64.6 | 62.7 | 68.5 | 64.1 | 63.5 | 67.1 | 63.3 | 62.6 |
| 10 Min.... | 63.0 | 63.9 | 63.9 | 62.3 | 63.6 | 63.5 | 63.5 | 63.9 | 62.7 | 63.4 | 63.0 | 63.2 | 64.6 | 63.2 | 62.5 |
| 11 Max.... | 64.2 | 65.1 | 65.1 | 63.4 | 65.0 | 64.9 | 64.3 | 65.3 | 63.7 | 64.7 | 63.8 | 64.0 | 65.7 | 64.1 | 63.1 |
| 11 Min.... | 61.6 | 63.7 | 64.0 | 60.4 | 63.6 | 64.0 | 62.5 | 64.1 | 63.4 | 62.0 | 62.5 | 63.6 | 64.3 | 64.0 | 63.0 |
| 13 Max.... | 56.6 | 55.8 | 56.1 | 56.4 | 55.9 | 57.5 | 56.1 | 56.9 | 59.9 | 55.5 | 55.2 | 59.4 | 55.2 | 60.9 | 62.5 |
| 13 Min.... | 45.9 | 52.4 | 54.5 | 43.9 | 51.8 | 56.0 | 48.9 | 55.1 | 58.0 | 49.0 | 52.5 | 57.4 | 52.3 | 59.0 | 61.5 |
| 14 Max.... | 59.1 | 56.1 | 55.2 | 60.7 | 57.1 | 56.0 | 57.2 | 55.0 | 57.2 | 56.9 | 53.4 | 56.6 | 55.0 | 58.0 | 59.5 |
| 14 Min.... | 47.5 | 52.1 | 53.6 | 47.0 | 51.9 | 54.9 | 49.0 | 53.9 | 56.1 | 48.9 | 52.0 | 55.7 | 51.9 | 56.7 | 58.6 |
| 15 Max.... | 59.6 | 57.1 | 56.4 | 60.6 | 57.7 | 56.9 | 57.9 | 55.4 | 56.3 | 57.9 | 54.1 | 56.2 | 55.9 | 56.6 | 59.1 |
| 15 Min.... | 51.0 | 54.2 | 55.7 | 50.3 | 54.4 | 56.1 | 51.8 | 54.6 | 56.0 | 51.6 | 53.1 | 55.9 | 53.4 | 56.1 | 57.4 |
| 16 Max.... | 55.7 | 56.0 | 56.8 | 55.8 | 56.3 | 57.5 | 54.9 | 56.1 | 56.4 | 55.1 | 55.0 | 56.5 | 55.1 | 56.4 | 57.1 |
| 16 Min.... | 53.1 | 55.2 | 56.1 | 52.6 | 55.3 | 56.9 | 53.4 | 55.6 | 56.3 | 53.5 | 53.9 | 56.4 | 54.6 | 56.3 | 56.8 |
| 17 Max.... | 57.7 | 56.5 | 56.4 | 57.8 | 56.6 | 56.8 | 56.8 | 55.7 | 56.3 | 57.1 | 54.4 | 56.3 | 56.0 | 56.1 | 58.2 |
| 17 Min.... | 53.8 | 55.0 | 55.8 | 53.1 | 55.1 | 56.5 | 53.8 | 55.3 | 56.0 | 54.0 | 53.7 | 56.1 | 54.4 | 55.8 | 57.2 |
| 18 Max.... | 52.6 | 54.5 | 56.1 | 51.6 | 54.4 | 57.0 | 53.0 | 56.1 | 56.5 | 53.0 | 55.1 | 56.9 | 54.8 | 56.3 | 57.5 |
| 18 Min.... | 51.0 | 53.5 | 55.0 | 49.7 | 53.2 | 55.7 | 51.5 | 54.8 | 56.1 | 51.6 | 52.9 | 56.1 | 53.6 | 56.1 | 57.4 |
| 20 Max.... | 47.5 | 49.0 | 50.4 | 47.0 | 49.1 | 51.8 | 47.1 | 50.5 | 53.4 | 47.3 | 49.2 | 53.0 | 48.6 | 53.4 | 56.1 |
| 20 Min.... | 44.0 | 47.7 | 49.8 | 43.6 | 47.4 | 51.1 | 44.9 | 49 7 | 52.6 | 45.1 | 47.1 | 52.0 | 47.2 | 52.5 | 55.5 |
| 21 Max.... | 47.8 | 48.7 | 49.6 | 47.8 | 48.9 | 50.9 | 46.9 | 49.1 | 51.9 | 46.9 | 48.4 | 51.5 | 47.9 | 52.0 | 55.2 |
| 21 Min.... | 43.6 | 47.1 | 48.6 | 43.5 | 47.1 | 50.1 | 43.9 | 48.4 | 51.2 | 44.1 | 46 1 | 50.9 | 46.4 | 51.2 | 54.4 |
| 22 Max.... | 44.1 | 46.4 | 48.4 | 43.9 | 46.4 | 50.0 | 43.5 | 48.1 | 50.9 | 43.5 | 47.4 | 50.6 | 45.9 | 50.8 | 53.8 |
| 22 Min.... | 41.5 | 45.5 | 47.6 | 40.0 | 45.4 | 49.1 | 41.8 | 47.0 | 50.1 | 43.0 | 44.9 | 49.6 | 45.1 | 50.0 | 53.2 |
| 23 Max.... | 41.5 | 44.0 | 46.5 | 40.2 | 43.8 | 48.1 | 40.8 | 45.8 | 49.3 | 41.4 | 44.9 | 48.7 | 43.4 | 49.3 | 52.4 |
| 23 Min.... | 38.9 | 42.9 | 45.2 | 38.8 | 42.8 | 46.5 | 39.5 | 44.2 | 48.1 | 39.7 | 43.1 | 47 8 | 41.7 | 48.2 | 52.1 |
| 24 Max.... | 47.8 | 46.5 | 46.2 | 47.6 | 46.7 | 46.9 | 46.5 | 47.1 | 47.5 | 47.0 | 43.6 | 47.2 | 43.8 | 47.0 | 50.9 |
| 24 Min.... | 41.4 | 43.1 | 44.9 | 40.6 | 43.3 | 45.9 | 40.9 | 44.0 | 46.9 | 41.3 | 42.0 | 46.7 | 41.0 | 45.9 | 49.8 |
| 25 Max.... | 46.0 | 46.2 | 46.6 | 45.6 | 46.4 | 47.5 | 45.6 | 45.7 | 47.5 | 45.9 | 45.4 | 47.5 | 43.7 | 46.2 | 49.4 |
| 25 Min.... | 39.9 | 44.3 | 45.6 | 38 1 | 44.0 | 46.8 | 40.8 | 44.9 | 47.3 | 41.1 | 42.9 | 47.2 | 42.1 | 45.8 | 49.0 |
| 27 Max.... | 45.0 | 46.1 | 47.2 | 44.9 | 46.3 | 48.1 | 44.4 | 46.5 | 47.6 | 44.8 | 45.2 | 47.7 | 44.4 | 45.9 | 48.5 |
| 27 Min.... | 43.9 | 45.9 | 46.8 | 43.3 | 45.9 | 47.9 | 44.0 | 46.0 | 47.5 | 44.4 | 44.2 | 47.5 | 44.0 | 44.9 | 48.4 |
| 28 Max.... | 44.9 | 45.8 | 46.6 | 44.4 | 45.8 | 47.6 | 44.3 | 45.6 | 47.2 | 44.8 | 43.5 | 47.6 | 44.2 | 46.1 | 48.4 |
| 28 Min.... | 43.4 | 45 0 | 46.1 | 42.9 | 45.1 | 47.3 | 42.9 | 45 4 | 47.2 | 43.5 | 43.1 | 47.3 | 43.6 | 45.9 | 48.3 |
| 29 Max.... | 45.1 | 45.9 | 46.6 | 44.6 | 46.1 | 47.5 | 44.9 | 45.7 | 47.3 | 45.3 | 44.8 | 47.4 | 44.2 | 45.9 | 48.3 |
| 29 Min.... | 43.4 | 45.0 | 46.1 | 42.5 | 45.1 | 47.1 | 43.0 | 45.5 | 47.1 | 43.5 | 43.1 | 47.2 | 43.4 | 45.7 | 48.1 |
| 30 Max.... | 42.2 | 44.1 | 45.9 | 41.0 | 44.0 | 47.1 | 41.7 | 45.5 | 47.3 | 42.4 | 44.6 | 47.4 | 43.1 | 45.8 | 48.1 |
| 30 Min.... | 39.9 | 42.7 | 44.9 | 38.6 | 42.5 | 46.0 | 39.5 | 41.0 | 46.6 | 40.6 | 42.9 | 46.5 | 41.6 | 45.5 | 48.0 |
| 31 Max.... | 40.7 | 42.8 | 44.0 | 40.9 | 42.7 | 45.2 | 40.9 | 43.5 | 46.0 | 40.9 | 42.5 | 46.1 | 40.8 | 45.0 | 47.9 |
| 31 Min.... | 38.6 | 41.6 | 43.5 | 38.8 | 41.4 | 44.7 | 38.9 | 42.9 | 45.6 | 39.4 | 40.9 | 45.4 | 40.0 | 44.4 | 47.5 |
| Ave. Max.. | 55.51 | 54.96 | 55.01 | 55.44 | 55.09 | 55.47 | 54.71 | 54.56 | 55.35 | 54.83 | 53.52 | 55.41 | 54.24 | 55.16 | 56.63 |
| Ave. Min.. | 50.15 | 52.82 | 53.94 | 49.25 | 52.63 | 54.64 | 50.74 | 53.58 | 54.81 | 50.89 | 52.03 | 54.85 | 52.21 | 54.60 | 56.14 |
| Ave. Range | 5.36 | 2.14 | 1.07 | 6.19 | 2.46 | 0.83 | 3.97 | 0.98 | 0.54 | 3.94 | 1.49 | 0.56 | 2.03 | 0.56 | 0.49 |

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TABLE 50.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, NOVEMBER, 1913.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 41.9 | 42.4 | 42.9 | 41.5 | 42.6 | 44.4 | 40.7 | 42.5 | 45.4 | 40.7 | 41.2 | 45.0 | 40.2 | 44.1 | 47.4 |
| 1 Min.... | 36.6 | 40.0 | 42.1 | 35.9 | 40.0 | 43.8 | 37.1 | 41.8 | 44.7 | 37.9 | 40.1 | 44.2 | 39.2 | 43.5 | 46 9 |
| 3 Max.... | 45.1 | 44.4 | 44.4 | 45.4 | 44.7 | 45.2 | 43.2 | 42.9 | 44.1 | 43.9 | 41.0 | 44.1 | 41.6 | 42.7 | 45.7 |
| 3 Min.... | 41.3 | 42.4 | 43.3 | 41.0 | 42.8 | 44.5 | 40.3 | 42.3 | 44.0 | 40.5 | 40.0 | 43.8 | 40.0 | 42.6 | 45 6 |
| 4 Max.... | 42.4 | 43.2 | 44.2 | 42.1 | 43.5 | 45.5 | 41.6 | 43.4 | 44.7 | 41.9 | 42.2 | 44.9 | 41.5 | 43.2 | 45.7 |
| 4 Min.... | 38.9 | 42.0 | 43.5 | 38.2 | 42.1 | 44.7 | 39.5 | 42 8 | 44.6 | 40.0 | 40.5 | 44.6 | 40.7 | 43.0 | 45.4 |
| 5 Max.... | 43.4 | 42.6 | 42.9 | 43.9 | 43.1 | 44.4 | 41.8 | 42.3 | 44.7 | 41.8 | 41.4 | 44.6 | 40.0 | 43.1 | 45.7 |
| 5 Min.... | 36.4 | 39.8 | 41.7 | 35.6 | 39.9 | 43.4 | 37.0 | 41.5 | 43.9 | 37.2 | 38.6 | 43.6 | 39.4 | 42.8 | 45.4 |
| 6 Max.... | 43.6 | 42.4 | 42.4 | 44.2 | 43.0 | 43.9 | 42.1 | 41.9 | 44.1 | 41.9 | 40.5 | 43.9 | 39.5 | 42.9 | 45.6 |
| 6 Min.... | 36.4 | 39.6 | 41.4 | 35.7 | 39.8 | 43.1 | 37.2 | 41.2 | 43.5 | 37.1 | 38.4 | 43.1 | 38.9 | 42.2 | 45.1 |
| 7 Max.... | 49.2 | 46.3 | 45.1 | 50.1 | 46.6 | 45.5 | 47.0 | 43.7 | 44.0 | 47.5 | 43.7 | 44.0 | 42.7 | 42.4 | 45.0 |
| 7 Min.... | 42.1 | 42.8 | 43.3 | 42.0 | 43.0 | 44.4 | 41.2 | 42.3 | 43.5 | 41.5 | 39.9 | 43.5 | 40.2 | 42.1 | 44.8 |
| 8 Max.... | 47.0 | 47.3 | 47.1 | 46.9 | 47.5 | 47.4 | 46.6 | 46.0 | 45.7 | 47.0 | 45.7 | 46.2 | 44.9 | 43.9 | 45.2 |
| 8 Min.... | 43.3 | 45.8 | 46.5 | 42.4 | 45.8 | 47.2 | 43.7 | 45.7 | 44.9 | 44.0 | 45.0 | 45.5 | 44.2 | 43.0 | 44.9 |
| 10 Max.... | 35.7 | 39.0 | 41.2 | 34.7 | 39.0 | 42.8 | 36.3 | 41.2 | 44.4 | 36.1 | 40.6 | 44.0 | 39.4 | 43.5 | 46.0 |
| 10 Min.... | 35.5 | 38.4 | 40.4 | 34.5 | 38.3 | 42.1 | 35.9 | 40.4 | 43.6 | 35.6 | 39.6 | 42.9 | 38.6 | 43.0 | 45.9 |
| 11 Max.... | 35.9 | 38.4 | 40.0 | 34.9 | 38.1 | 41.5 | 35.6 | 39.7 | 42.8 | 35.4 | 39.0 | 42.1 | 38.0 | 42.4 | 45.5 |
| 11 Min.... | 35.5 | 38.0 | 39.7 | 34.8 | 38.0 | 41.1 | 35.3 | 39.2 | 42.2 | 35.3 | 38.8 | 41.5 | 37.5 | 41.8 | 45.0 |
| 12 Max.... | 35.5 | 37.9 | 39.5 | 35.1 | 38.0 | 41.1 | 35.5 | 39.0 | 41.9 | 36.3 | 38.6 | 41.2 | 37.3 | 41.4 | 44.8 |
| 12 Min.... | 35.0 | 37.3 | 39.0 | 34.5 | 37.4 | 40.6 | 34.6 | 38.1 | 41.1 | 34.7 | 37.7 | 40.6 | 36.6 | 40 8 | 44.1 |
| 13 Max.... | 39.9 | 39.8 | 38.8 | 41.2 | 40.0 | 40.4 | 42.9 | 40.1 | 40.9 | 43.9 | 40.5 | 41.2 | 38.6 | 40.5 | 43.6 |
| 13 Min.... | 34.6 | 36.9 | 38.1 | 34.6 | 37.3 | 39.9 | 36.7 | 38.1 | 40.7 | 38.5 | 38.1 | 40.8 | 36.5 | 40.0 | 43 3 |
| 14 Max.... | 39.2 | 39.5 | 39.4 | 40.6 | 41.8 | 42.1 | 42.4 | 41.8 | 42.3 | 42.8 | 42.1 | 42.8 | 40.5 | 40.6 | 43.0 |
| 14 Min.... | 35.4 | 37.2 | 38.4 | 37.9 | 40.1 | 41.8 | 40.4 | 41.3 | 42.0 | 41.0 | 41.2 | 42.6 | 39.4 | 40.5 | 42.9 |
| 15 Max.... | 35.5 | 37.9 | 39.4 | 35.5 | 39.1 | 41.9 | 37.6 | 41.5 | 42.8 | 38.0 | 41.4 | 43.1 | 38.3 | 41.1 | 43.2 |
| 15 Min.... | 35.2 | 37.4 | 38.7 | 35.4 | 38.4 | 41.1 | 36.8 | 40.5 | 42 5 | 37.2 | 40.2 | 42.6 | 38.2 | 41.0 | 43 1 |
| 17 Max.... | 40.0 | 39.3 | 39.4 | 40.3 | 39.9 | 40.9 | 39.4 | 39.6 | 41.5 | 39.7 | 39.5 | 41.6 | 37.3 | 40.4 | 43.1 |
| 17 Min.... | 35.4 | 37.4 | 38.6 | 34.8 | 37.8 | 40.6 | 36.2 | 39.3 | 41.1 | 36.5 | 38.9 | 41.1 | 37.0 | 40.0 | 42.7 |
| 18 Max.... | 45.1 | 42.9 | 42.0 | 45.7 | 43.5 | 42.8 | 43.8 | 41.5 | 41.8 | 44.5 | 41.4 | 42.0 | 40.4 | 40.1 | 42.6 |
| 18 Min.... | 40.8 | 40.3 | 40.4 | 41.2 | 40.7 | 41.6 | 40.0 | 40.4 | 41.4 | 40.6 | 40.0 | 41.4 | 38.2 | 39.9 | 42.4 |
| 19 Max.... | 53.1 | 49.2 | 47.1 | 53.6 | 49.6 | 46.9 | 51.6 | 46.3 | 43.8 | 52.1 | 46.4 | 44.8 | 47.1 | 42.0 | 42.8 |
| 19 Min.... | 49.5 | 45.9 | 44.4 | 50.1 | 46.5 | 44.7 | 49.1 | 44.7 | 42.7 | 48.5 | 44.0 | 43.4 | 43.6 | 40.7 | 42.5 |
| 20 Max.... | 54.0 | 51.3 | 49.9 | 54.3 | 51.4 | 49.4 | 52.9 | 49.2 | 46.5 | 53.4 | 49.1 | 47.9 | 50.0 | 44.9 | 44.2 |
| 20 Min.... | 52.4 | 50.4 | 49.0 | 52.5 | 50 7 | 48.7 | 51.6 | 48.2 | 45.5 | 52.3 | 48.4 | 46.7 | 49.0 | 43.8 | 43.4 |
| 21 Max.... | 55.8 | 53.4 | 51.7 | 56.2 | 53.5 | 51.1 | 55.0 | 51.2 | 48.5 | 55.5 | 51.7 | 49.7 | 52.4 | 47.1 | 46.2 |
| 21 Min.... | 53.5 | 52.1 | 50.9 | 53.2 | 52.1 | 50.5 | 53.0 | 50.4 | 47.8 | 53.5 | 50.3 | 49.1 | 51.2 | 46 2 | 45.3 |
| 22 Max.... | 57.0 | 54.1 | 52.6 | 57.4 | 54.1 | 52.0 | 56.1 | 52.5 | 50.0 | 56.6 | 52.5 | 51.1 | 53.7 | 49.1 | 48.0 |
| 22 Min.... | 53.3 | 52.8 | 52.0 | 53.0 | 52 8 | 51 5 | 53.4 | 51.9 | 49.5 | 53.6 | 52.0 | 50.8 | 52.4 | 48.3 | 47.3 |
| 24 Max.... | 42.5 | 45.1 | 47.4 | 41.4 | 44.7 | 48.3 | 42.7 | 48.1 | 49.9 | 42.8 | 47.6 | 50.0 | 46.8 | 50.0 | 50.2 |
| 24 Min.... | 40 2 | 43.8 | 45 9 | 38.5 | 43.7 | 46.6 | 42.0 | 46.4 | 48.7 | 42.1 | 45.9 | 49.1 | 45.6 | 49.1 | 50.1 |
| 25 Max.... | 39.9 | 41.6 | 44.1 | 39.5 | 41.5 | 45.5 | 39.3 | 44.8 | 47.5 | 39.9 | 44.0 | 47.1 | 43.8 | 48.2 | 50.2 |
| 25 Min.... | 37.3 | 40 8 | 42 3 | 36.2 | 40 5 | 44.1 | 37.8 | 43.1 | 46.1 | 37.9 | 42.5 | 45.6 | 42.1 | 47.0 | 49 4 |
| 26 Max.... | 42.0 | 42.8 | 43.4 | 41.5 | 42.9 | 44.4 | 41.6 | 43.0 | 45.2 | 42.0 | 43.0 | 44.9 | 42.5 | 46.0 | 48.6 |
| 26 Min.... | 40.4 | 41.8 | 43.0 | 40 0 | 42.0 | 44.2 | 40.3 | 42.9 | 44.8 | 40.7 | 42.6 | 44.6 | 42.0 | 45.4 | 48.0 |
| 27 Max.... | 40.6 | 42.1 | 43.0 | 40.2 | 42.1 | 44.4 | 40.6 | 42.9 | 44.7 | 41.2 | 42.7 | 44.6 | 42.0 | 44.9 | 47.4 |
| 27 Min.... | 39.7 | 41.8 | 43.0 | 39.0 | 41.8 | 44.0 | 39.9 | 42 6 | 44.4 | 40.4 | 42.5 | 44.2 | 41.7 | 44.5 | 46.9 |
| 28 Max.... | 42.4 | 42.5 | 42.9 | 42.3 | 42.6 | 43.9 | 41.6 | 42.5 | 44.1 | 42.4 | 42.5 | 44.1 | 41.8 | 44.1 | 46.4 |
| 28 Min.... | 39.9 | 41.5 | 42.6 | 39.4 | 41.6 | 43.7 | 39.7 | 42.2 | 43.9 | 40.5 | 42.1 | 43 9 | 41.4 | 43.8 | 46.1 |
| 29 Max.... | 44.0 | 43.9 | 44.1 | 43.9 | 44.1 | 44.9 | 43.4 | 43.4 | 44.1 | 43.9 | 43.7 | 44.4 | 42.7 | 43.7 | 45.6 |
| 29 Min.... | 42.9 | 43.2 | 43.6 | 42.6 | 43.4 | 44.5 | 42.3 | 43.1 | 43.9 | 43.0 | 43.1 | 44.1 | 42.4 | 43.6 | 45.5 |
| Ave. Max.. | 43.63 | 43.57 | 43.80 | 43.70 | 43.88 | 44.82 | 43.25 | 43.64 | 44.62 | 43.85 | 43.28 | 44.77 | 42.56 | 43.89 | 45.68 |
| Ave. Min.. | 40.46 | 42.38 | 42.87 | 40.12 | 42.26 | 44.10 | 40.84 | 42.82 | 44.04 | 41.20 | 42.02 | 44.13 | 41.44 | 43.14 | 45.28 |
| Ave. Range | 3.17 | 1.19 | 0.93 | 3.58 | 1.62 | 0.72 | 2.41 | 0.82 | 0.58 | 2.45 | 1.26 | 0.64 | 1.12 | 0.55 | 0.40 |

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BEGINNING WITH THIRD YEAR.

TABLE 51.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, DECEMBER, 1913.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | Max. | 50.9 | 49.6 | 48.9 | 50.7 | 49.7 | 48.6 | 50.0 | 48.1 | 46.6 | 50.6 | 48.5 | 47.4 | 48.4 | 45.5 | 45.9 |
| | Min. | 50.4 | 49.1 | 48.2 | 50.3 | 49.3 | 48.1 | 49.5 | 47.4 | 45.9 | 50.1 | 47.7 | 46.6 | 47.0 | 44.9 | 45.6 |
| 2 | Max. | 51.5 | 50.3 | 49.6 | 51.9 | 50.3 | 49.6 | 50.7 | 49.1 | 47.6 | 51.2 | 49.5 | 48.5 | 49.5 | 46.9 | 46.8 |
| | Min. | 49.9 | 49.5 | 49.1 | 49.5 | 48.9 | 49.0 | 49.5 | 48.6 | 47.4 | 50.0 | 48.9 | 48.1 | 48.7 | 46.4 | 46.3 |
| 3 | Max. | 47.9 | 49.2 | 49.5 | 47.2 | 49.1 | 49.5 | 48.4 | 49.3 | 48.4 | 48.8 | 49.4 | 49.0 | 48.9 | 47.8 | 48.0 |
| | Min. | 46.6 | 48.3 | 48.6 | 46.0 | 48.1 | 48.9 | 47.4 | 48.6 | 48.3 | 47.8 | 48.6 | 48.9 | 48.4 | 47.5 | 47.4 |
| 4 | Max. | 44.9 | 45.5 | 46.3 | 44.5 | 45.4 | 47.1 | 44.6 | 46.9 | 48.0 | 44.9 | 47.4 | 48.3 | 45.5 | 47.7 | 48.4 |
| | Min. | 41.3 | 44.1 | 45.5 | 40.4 | 43.9 | 46.4 | 41.9 | 45.8 | 47.1 | 42.4 | 45.6 | 47.1 | 44.8 | 47.2 | 48.2 |
| 5 | Max. | 43.5 | 44.3 | 45.0 | 43.3 | 44.3 | 46.0 | 43.4 | 4.50 | 46.7 | 43.3 | 44.6 | 46.7 | 43.9 | 46.6 | 48.4 |
| | Min. | 40.1 | 43 1 | 44.4 | 39.2 | 43.0 | 45.4 | 40.7 | 44.4 | 46.0 | 41.1 | 44.1 | 45.9 | 43.3 | 46.3 | 48.0 |
| 6 | Max. | 42.4 | 43.0 | 44.0 | 42.0 | 43.0 | 45.1 | 41.8 | 43.9 | 45.7 | 42.2 | 43.4 | 45.5 | 42.8 | 45.7 | 47.9 |
| | Min. | 38.9 | 41.9 | 43.5 | 37.6 | 41.8 | 44.5 | 39.4 | 43.2 | 45.1 | 39.5 | 42.7 | 44.8 | 41.4 | 45.2 | 47.3 |
| 8 | Max. | 35.0 | 39.0 | 41.3 | 34.9 | 39.5 | 43.1 | 36.5 | 41.5 | 44.4 | 36.5 | 41.1 | 44.0 | 40.5 | 44.3 | 47.3 |
| | Min. | 34.4 | 37.9 | 40.1 | 34.5 | 38.4 | 42.1 | 35.8 | 40.4 | 43.4 | 35.7 | 39.8 | 42.8 | 39.4 | 43.6 | 46.4 |
| 9 | Max. | 33.4 | 37.1 | 39.3 | 33.1 | 37.6 | 41.5 | 34.9 | 39.7 | 42.7 | 34.5 | 39.4 | 42.0 | 38.4 | 42.9 | 45.6 |
| | Min. | 33.0 | 36.4 | 38.5 | 32.9 | 36.9 | 40.6 | 34.4 | 38.7 | 42.0 | 34.0 | 38.0 | 41.2 | 37.4 | 42 0 | 45.2 |
| 10 | Max. | 33.6 | 36.4 | 38.1 | 33.5 | 36.8 | 40.2 | 34.3 | 38.4 | 41.4 | 34.2 | 37.5 | 40.5 | 36.8 | 41.5 | 44.6 |
| | Min. | 33.5 | 36.2 | 37.9 | 33.3 | 36.8 | 40.0 | 34.1 | 38.0 | 41.0 | 34.1 | 37.3 | 40.2 | 36.1 | 40.9 | 44.1 |
| 11 | Max. | 33.6 | 36.4 | 38.0 | 33.4 | 37.0 | 39.9 | 34.2 | 37.9 | 40.8 | 34.4 | 37.4 | 40.0 | 36.5 | 40.4 | 43.5 |
| | Min. | 33.1 | 35.9 | 37.4 | 32.8 | 36.3 | 39.5 | 33.7 | 37.3 | 4.02 | 33.9 | 36.8 | 39.6 | 35.9 | 39.9 | 43.0 |
| 12 | Max. | 33.4 | 36.8 | 37.4 | 33.4 | 36.3 | 39.5 | 33.7 | 37.2 | 40.0 | 33.8 | 36.7 | 39.4 | 35.7 | 39.5 | 42.8 |
| | Min. | 33.1 | 35.5 | 37.1 | 32.7 | 36.0 | 38.9 | 33.4 | 36.8 | 39.6 | 33.5 | 36?4 | 38.9 | 35.3 | 38.9 | 42.0 |
| 13 | Max | 37.2 | 37.0 | 37.5 | 37.4 | 37.6 | 39.1 | 33.6 | 36.9 | 39.4 | 34.1 | 36.5 | 38.9 | 35.2 | 38.8 | 42.1 |
| | Min. | 33.8 | 35.9 | 37.1 | 33.6 | 36.4 | 39.0 | 33 5 | 36.6 | 39.1 | 34.0 | 36.4 | 38.7 | 34.2 | 38.4 | 41.4 |
| 15 | Max. | 34.1 | 36.6 | 37.9 | 33.5 | 36.8 | 39.4 | 34.4 | 37.2 | 39.4 | 34.9 | 37.1 | 39.2 | 35.0 | 38.0 | 40.9 |
| | Min. | 33.7 | 36.1 | 37.4 | 33 1 | 36.2 | 38.9 | 34.0 | 37.0 | 39.1 | 34.5 | 36.9 | 38.8 | 34.0 | 37.7 | 40.5 |
| 16 | Max. | 37.8 | 38.0 | 38.2 | 37.6 | 38.3 | 39.4 | 36.6 | 37.2 | 39.0 | 37.3 | 37.3 | 38.6 | 33.9 | 37.6 | 40.5 |
| | Min. | 35.0 | 36.4 | 37.3 | 34.8 | 36.5 | 38.7 | 34.0 | 36.8 | 38.9 | 34.5 | 36.6 | 38.7 | 33.8 | 37.5 | 40.2 |
| 17 | Max | 36.1 | 37.3 | 38.1 | 35.7 | 37.6 | 39.6 | 35.7 | 37.5 | 39.3 | 37.5 | 37.7 | 39.2 | 34.7 | 37.5 | 40.3 |
| | Min. | 35.2 | 36.9 | 38.0 | 34.6 | 37.1 | 39.2 | 34.8 | 37.3 | 39.0 | 35.5 | 37.4 | 39.0 | 33.8 | 37.4 | 40.0 |
| 18 | Max. | 34.4 | 36.5 | 37.8 | 33.7 | 36.6 | 39.0 | 34.6 | 37.4 | 39.3 | 35.1 | 37.4 | 39.1 | 34.6 | 37.4 | 40.0 |
| | Min. | 34.1 | 36.4 | 37.6 | 33.6 | 36.5 | 38.7 | 34.3 | 37.2 | 39 1 | 34.9 | 37.2 | 39 0 | 34.5 | 37.2 | 39.9 |
| 19 | Max. | 33.3 | 35.9 | 37.2 | 32.5 | 36.0 | 38.6 | 33.9 | 36.9 | 38.9 | 34.3 | 37.0 | 38.8 | 34.5 | 37.4 | 40.1 |
| | Min. | 33.1 | 35.4 | 36.7 | 32.1 | 35.4 | 38 2 | 33 5 | 36.6 | 38.6 | 34.0 | 36.5 | 38.5 | 33 4 | 37.1 | 39.8 |
| 20 | Max. | 33.1 | 35.2 | 36.6 | 32.6 | 35.5 | 38.2 | 33.4 | 36.4 | 38.7 | 33.8 | 36.3 | 38.4 | 34.4 | 37.1 | 39.8 |
| | Min. | 33.1 | 35.1 | 36.5 | 32.4 | 35.3 | 37.9 | 33.4 | 36 3 | 38.4 | 33.6 | 36.1 | 38 1 | 34.3 | 37.0 | 39.7 |
| 22 | Max. | 32.2 | 34.4 | 35.9 | 31.4 | 34.4 | 37.5 | 32.8 | 35.9 | 38.1 | 32.6 | 35.5 | 37.9 | 34.1 | 37.1 | 39.6 |
| | Min. | 30.1 | 33.9 | 35.2 | 26.5 | 33.9 | 36.9 | 32.3 | 35.5 | 37.8 | 32 2 | 35.0 | 37.2 | 33.7 | 36.6 | 39.2 |
| 23 | Max. | 32.3 | 33.9 | 35.3 | 31.8 | 33.9 | 36.8 | 32.3 | 35.1 | 37.5 | 32.4 | 34.8 | 37.1 | 33.5 | 36.5 | 39.0 |
| | Min. | 31.5 | 33.6 | 35.0 | 30.5 | 33.6 | 36.6 | 32.1 | 35.0 | 37.3 | 32.2 | 34.7 | 36.8 | 33.4 | 36.4 | 38.9 |
| 24 | Max. | 32.3 | 33.8 | 35.1 | 32.1 | 33.9 | 36.6 | 32.2 | 35.1 | 37.1 | 32.5 | 34.6 | 36.6 | 33.3 | 36.2 | 38.7 |
| | Min. | 32.2 | 33.6 | 34.9 | 32.0 | 33.8 | 36.4 | 32.1 | 34.8 | 37.0 | 32.4 | 34.4 | 36.4 | 32.3 | 35.8 | 38.2 |
| 26 | Max. | 32.8 | 34.3 | 35.3 | 32.4 | 34.7 | 36.8 | 32.5 | 34.9 | 36.9 | 32.9 | 34.8 | 36.7 | 33.1 | 35.8 | 38.4 |
| | Min. | 32.7 | 34.1 | 35.3 | 32 3 | 34.5 | 36.8 | 32.4 | 34.8 | 36.5 | 32.7 | 34.7 | 36.5 | 32.5 | 35.7 | 38.1 |
| 27 | Max. | 32.7 | 34.7 | 35.6 | 32.0 | 34.9 | 37.0 | 32.6 | 35.3 | 37.1 | 33.2 | 35.1 | 36.8 | 33.6 | 36.0 | 38.5 |
| | Min. | 32 0 | 33.6 | 34.7 | 31.0 | 33.7 | 36.2 | 32.0 | 34.4 | 36.3 | 32.3 | 34.2 | 36.1 | 32.7 | 35.1 | 38.2 |
| 29 | Max. | 32.3 | 33.8 | 34.8 | 32.0 | 34.0 | 37.0 | 32.1 | 34.3 | 36.2 | 32.4 | 34.2 | 35.9 | 32.5 | 34.9 | 37.3 |
| | Min. | 32.2 | 33.7 | 34.7 | 31.9 | 33.9 | 36.0 | 32.0 | 34.2 | 36.0 | 32.3 | 34.1 | 35.8 | 31.6 | 34.7 | 37.2 |
| 30 | Max. | 32.3 | 34.0 | 34.7 | 32.1 | 34.1 | 36.9 | 32.1 | 34.1 | 36.3 | 32.5 | 34.1 | 35.9 | 32.6 | 34.6 | 37.1 |
| | Min. | 32.0 | 33 5 | 34.3 | 31 6 | 33.6 | 35 8 | 31.7 | 33.9 | 35.6 | 32 2 | 33.9 | 35.6 | 32.3 | 34 3 | 36.8 |
| 31 | Max. | 32.4 | 33.8 | 34.9 | 32.3 | 34.2 | 36.2 | 32.1 | 34.2 | 36.1 | 32.6 | 34.4 | 36.0 | 32.7 | 34.8 | 37.3 |
| | Min. | 32.3 | 33.7 | 34 7 | 32 1 | 34.0 | 36.1 | 31.8 | 34.0 | 36 0 | 32.5 | 34.1 | 35.8 | 30.3 | 34.6 | 36.7 |
| Ave. | Max. | 36.75 | 38.34 | 39.32 | 36.42 | 38.52 | 40.70 | 36.67 | 39.05 | 40.83 | 37.02 | 38.91 | 40.64 | 37.48 | 39.94 | 42.26 |
| | Min. | 35.67 | 37.68 | 38.83 | 35.06 | 37.84 | 40.18 | 35.91 | 38.60 | 40.41 | 36.23 | 38.39 | 40.20 | 36.71 | 39.55 | 41.86 |
| | Range | 1.08 | 0.66 | 0.49 | 1.36 | 0.68 | 0.52 | 0.76 | 0.45 | 0.42 | 0.79 | 0.52 | 0.44 | 0.77 | 0.39 | 0.40 |

TABLE 52.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, JANUARY, 1914.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 32.5 | 34.1 | 34.8 | 32.3 | 34.2 | 36.1 | 32.1 | 34.2 | 36.1 | 32.6 | 34.3 | 35.8 | 32.3 | 34.8 | 37.1 |
| 1 Min.... | 32.3 | 33.8 | 34.7 | 32.1 | 34.0 | 36.0 | 32.0 | 34.0 | 36.0 | 32.5 | 34.1 | 35.6 | 31.6 | 34.4 | 36.8 |
| 2 Max.... | 32.5 | 34.0 | 34.9 | 32.2 | 34.2 | 36.1 | 32.1 | 34.3 | 36.0 | 32.7 | 34.3 | 35.8 | 32.6 | 34.7 | 37.2 |
| 2 Min.... | 32.4 | 33.8 | 34.8 | 32.1 | 34.1 | 35.8 | 32.1 | 34.1 | 35.8 | 32.6 | 34.1 | 35.7 | 32.4 | 34.5 | 37.0 |
| 3 Max.... | 32.7 | 34.1 | 35.1 | 32.6 | 34.3 | 36.1 | 32.3 | 34.3 | 36.0 | 32.8 | 34.5 | 35.9 | 32.7 | 34.7 | 37.1 |
| 3 Min.... | 32.5 | 34.0 | 34.8 | 32.3 | 34.2 | 36.0 | 32.1 | 34.1 | 35.9 | 32.6 | 34.3 | 35.7 | 32.3 | 34.5 | 36.9 |
| 5 Max.... | 33.1 | 34.4 | 35.1 | 32.9 | 34.6 | 36.3 | 32.4 | 34.4 | 36.0 | 33.1 | 34.6 | 36.0 | 32.9 | 34.8 | 37.1 |
| 5 Min.... | 32.9 | 34.3 | 35.0 | 32.7 | 34.5 | 36.2 | 32.3 | 34.3 | 35.9 | 33.1 | 34.4 | 35.9 | 32.8 | 34.6 | 37.0 |
| 6 Max.... | 33.3 | 34.5 | 35.1 | 33.0 | 34.6 | 36.3 | 32.4 | 34.4 | 36.0 | 33.2 | 34.6 | 36.0 | 32.9 | 34.8 | 37.1 |
| 6 Min.... | 33.2 | 34.4 | 35.1 | 33.0 | 34.5 | 36.2 | 32.3 | 34.3 | 35.9 | 33.1 | 34.5 | 35.9 | 32.4 | 34.6 | 36.9 |
| 7 Max.... | 33.2 | 34.4 | 35.4 | 33.1 | 34.6 | 36.3 | 32.4 | 34.4 | 35.9 | 33.2 | 34.7 | 36.1 | 32.8 | 34.7 | 36.9 |
| 7 Min.... | 33.2 | 34.4 | 35.1 | 33.0 | 34.6 | 36.2 | 32.3 | 34.3 | 35.9 | 33.2 | 34.5 | 35.9 | 32.5 | 34.6 | 36.8 |
| 8 Max.... | 33.4 | 34.6 | 35.2 | 33.1 | 34.7 | 36.4 | 32.4 | 34.4 | 36.0 | 33.4 | 34.7 | 35.9 | 32.8 | 34.6 | 36.9 |
| 8 Min.... | 33.2 | 34.4 | 35.1 | 32.9 | 34.6 | 36.2 | 32.3 | 34.2 | 35.9 | 33.3 | 34.5 | 35.9 | 32.7 | 34.5 | 36.8 |
| 9 Max.... | 33.4 | 34.6 | 35.2 | 33.1 | 34.7 | 36.3 | 32.5 | 34.4 | 35.9 | 33.4 | 34.7 | 36.1 | 32.7 | 34.7 | 36.9 |
| 9 Min.... | 33.3 | 34.4 | 35.1 | 33.0 | 34.6 | 36.2 | 32.4 | 34.3 | 35.0 | 33.4 | 34.6 | 36.0 | 32.6 | 34.5 | 36.8 |
| 10 Max.... | 33.5 | 34.6 | 35.3 | 33.3 | 34.7 | 36.3 | 32.7 | 34.5 | 36.0 | 33.6 | 34.9 | 36.2 | 32.9 | 34.7 | 36.9 |
| 10 Min.... | 33.4 | 34.5 | 35.2 | 33.1 | 34.6 | 36.2 | 32.5 | 34.4 | 36.0 | 33.5 | 34.9 | 36.1 | 32.7 | 34.6 | 36.8 |
| 12 Max.... | 33.5 | 34.7 | 35.5 | 33.3 | 34.7 | 36.4 | 32.9 | 34.8 | 36.2 | 33.9 | 35.3 | 36.4 | 33.1 | 34.9 | 37.0 |
| 12 Min.... | 33.4 | 34.7 | 35.4 | 33.1 | 34.6 | 36.2 | 32.8 | 34.6 | 36.1 | 33.9 | 35.1 | 36.3 | 33.0 | 34.7 | 37.0 |
| 13 Max.... | 33.9 | 35.1 | 35.8 | 33.4 | 35.0 | 36.6 | 33.3 | 35.1 | 36.5 | 34.2 | 35.6 | 36.7 | 33.4 | 35.2 | 37.4 |
| 13 Min.... | 33.4 | 34.5 | 35.3 | 32.9 | 34.5 | 36.1 | 32.9 | 34.8 | 36.1 | 33.7 | 35.0 | 36.3 | 33.0 | 34.7 | 36.9 |
| 14 Max.... | 33.8 | 35.0 | 35.8 | 33.3 | 34.9 | 36.7 | 33.4 | 35.3 | 36.7 | 34.2 | 35.5 | 36.8 | 33.5 | 35.2 | 37.4 |
| 14 Min.... | 33.6 | 34.8 | 35.5 | 33.1 | 34.7 | 36.4 | 33.1 | 34.9 | 36.4 | 33.9 | 35.3 | 36.4 | 33.3 | 35.0 | 37.2 |
| 15 Max.... | 33.7 | 34.7 | 35.5 | 33.1 | 34.8 | 36.4 | 33.1 | 34.9 | 36.4 | 34.0 | 35.3 | 36.4 | 33.4 | 35.1 | 37.1 |
| 15 Min.... | 33.4 | 34.7 | 35.4 | 33.1 | 34.6 | 36.3 | 33.0 | 34.9 | 36.4 | 33.9 | 35.2 | 36.4 | 33.3 | 34.9 | 37.1 |
| 16 Max.... | 33.8 | 34.9 | 35.6 | 33.2 | 34.8 | 36.4 | 33.3 | 35.0 | 36.4 | 34.0 | 35.2 | 36.5 | 33.4 | 35.0 | 37.1 |
| 16 Min.... | 33.6 | 34.7 | 35.5 | 33.2 | 34.6 | 36.3 | 33.0 | 34.9 | 36.3 | 33.9 | 35.1 | 36.4 | 33.3 | 34.9 | 36.9 |
| 17 Max.... | 33.7 | 35.0 | 35.6 | 33.4 | 34.8 | 36.4 | 33.3 | 35.0 | 36.4 | 34.1 | 35.3 | 36.5 | 33.4 | 35.1 | 37.2 |
| 17 Min.... | 33.7 | 34.9 | 35.6 | 33.3 | 34.7 | 36.4 | 33.1 | 34.9 | 36.3 | 34.0 | 35.2 | 36.4 | 33.3 | 34.9 | 37.1 |
| 19 Max.... | 33.9 | 34.9 | 35.6 | 33.4 | 34.9 | 36.4 | 33.3 | 35.0 | 36.4 | 34.1 | 35.4 | 36.5 | 33.4 | 35.0 | 37.1 |
| 19 Min.... | 33.7 | 34.9 | 35.5 | 33.4 | 34.9 | 36.4 | 33.2 | 34.9 | 36.3 | 34.1 | 35.3 | 36.4 | 33.3 | 34.9 | 37.0 |
| 20 Max.... | 33.8 | 34.9 | 35.6 | 33.4 | 34.9 | 36.4 | 33.3 | 35.0 | 36.4 | 34.1 | 35.4 | 36.5 | 33.4 | 35.0 | 37.1 |
| 20 Min.... | 33.7 | 34.9 | 35.4 | 33.3 | 34.8 | 36.4 | 33.2 | 34.9 | 36.3 | 34.0 | 35.3 | 36.4 | 33.3 | 34.9 | 36.9 |
| 21 Max.... | 33.9 | 35.0 | 35.6 | 33.6 | 34.9 | 36.5 | 33.3 | 35.1 | 36.4 | 34.2 | 35.4 | 36.5 | 33.4 | 35.1 | 37.1 |
| 21 Min.... | 33.8 | 34.9 | 35.6 | 33.5 | 34.9 | 36.4 | 33.2 | 35.0 | 36.3 | 34.1 | 35.4 | 36.4 | 33.4 | 34.9 | 37.1 |
| 22 Max.... | 34.0 | 35.0 | 35.7 | 33.6 | 35.1 | 36.4 | 33.4 | 35.0 | 36.4 | 34.3 | 35.5 | 36.6 | 33.5 | 35.1 | 37.2 |
| 22 Min.... | 33.9 | 34.9 | 35.5 | 33.5 | 34.9 | 36.4 | 33.3 | 35.0 | 36.3 | 34.1 | 35.4 | 36.4 | 33.4 | 34.9 | 37.0 |
| 23 Max.... | 33.9 | 34.9 | 35.6 | 33.6 | 35.0 | 36.4 | 33.4 | 34.9 | 36.3 | 34.2 | 35.5 | 36.5 | 33.4 | 34.9 | 37.0 |
| 23 Min.... | 33.9 | 34.8 | 35.4 | 33.5 | 34.9 | 36.3 | 33.2 | 34.9 | 36.1 | 34.1 | 35.2 | 36.3 | 33.3 | 34.8 | 36.9 |
| 24 Max.... | 34.0 | 34.9 | 35.6 | 33.6 | 34.9 | 36.4 | 33.5 | 35.0 | 36.4 | 34.2 | 35.4 | 36.5 | 33.5 | 35.0 | 37.1 |
| 24 Min.... | 33.9 | 34.7 | 35.4 | 33.4 | 34.7 | 36.2 | 33.4 | 35.0 | 36.3 | 34.1 | 35.1 | 36.4 | 33.4 | 34.9 | 37.0 |
| 26 Max.... | 33.8 | 34.9 | 35.7 | 33.3 | 34.9 | 36.5 | 33.4 | 35.1 | 36.4 | 34.0 | 35.4 | 36.4 | 33.4 | 34.9 | 36.9 |
| 26 Min.... | 33.6 | 34.9 | 35.6 | 33.1 | 34.7 | 36.2 | 33.3 | 35.0 | 36.3 | 34.0 | 35.2 | 36.3 | 33.4 | 34.7 | 36.7 |
| 27 Max.... | 33.6 | 34.8 | 35.5 | 33.3 | 34.8 | 36.3 | 33.3 | 35.0 | 36.3 | 33.9 | 35.3 | 36.3 | 33.3 | 34.7 | 36.6 |
| 27 Min.... | 33.4 | 34.5 | 35.2 | 33.1 | 34.5 | 36.2 | 33.3 | 34.9 | 36.2 | 33.8 | 34.9 | 36.0 | 33.3 | 34.6 | 36.6 |
| 28 Max.... | 33.7 | 34.7 | 35.5 | 33.4 | 34.7 | 36.2 | 33.4 | 34.9 | 36.1 | 34.0 | 35.1 | 36.1 | 33.4 | 34.7 | 36.6 |
| 28 Min.... | 33.6 | 34.6 | 35.2 | 33.2 | 34.6 | 36.2 | 33.3 | 34.6 | 35.7 | 33.9 | 34.9 | 36.0 | 33.2 | 34.6 | 36.6 |
| 29 Max.... | 41.5 | 39.7 | 38.1 | 42.3 | 39.7 | 37.6 | 38.3 | 35.6 | 35.8 | 41.1 | 37.7 | 36.6 | 33.4 | 34.4 | 36.4 |
| 29 Min.... | 37.4 | 35.5 | 35.5 | 37.5 | 35.5 | 36.1 | 33.1 | 34.5 | 35.6 | 36.2 | 35.1 | 35.9 | 33.3 | 34.4 | 36.1 |
| 30 Max.... | 35.0 | 36.9 | 37.5 | 34.4 | 36.9 | 38.0 | 34.9 | 36.7 | 36.9 | 35.9 | 37.6 | 37.8 | 33.4 | 34.6 | 36.3 |
| 30 Min.... | 34.0 | 35.6 | 36.7 | 33.6 | 35.8 | 37.4 | 34.0 | 36.1 | 36.8 | 34.7 | 36.6 | 37.5 | 33.3 | 34.4 | 36.2 |
| 31 Max.... | 33.4 | 35.1 | 36.1 | 33.0 | 35.1 | 37.0 | 33.5 | 35.7 | 36.9 | 33.9 | 35.9 | 37.1 | 33.4 | 34.6 | 36.5 |
| 31 Min.... | 33.4 | 34.9 | 35.8 | 32.9 | 34.9 | 36.7 | 33.4 | 35.5 | 36.8 | 33.8 | 35.6 | 36.9 | 33.3 | 34.5 | 36.3 |
| Ave. Max.. | 33.87 | 34.98 | 35.63 | 33.56 | 35.01 | 36.49 | 33.24 | 34.90 | 36.27 | 34.09 | 35.30 | 36.39 | 33.17 | 34.85 | 36.97 |
| Ave. Min.. | 33.55 | 34.64 | 35.35 | 33.22 | 34.68 | 36.28 | 32.89 | 34.71 | 36.14 | 33.76 | 34.99 | 36.21 | 33.00 | 34.68 | 36.83 |
| Ave. Range | 0.32 | 0.34 | 0.28 | 0.34 | 0.32 | 0.21 | 0.35 | 0.19 | 0.13 | 0.33 | 0.31 | 0.18 | 0.17 | 0.17 | 0.14 |

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TABLE 53.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, FEBRUARY, 1914.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum, | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 | Max.... | 33.6 | 35.0 | 35.8 | 33.4 | 35.0 | 36.6 | 33.4 | 35.4 | 36.7 | 34.0 | 35.4 | 36.6 | 33.6 | 35.0 | 37.1 |
| | Min.... | 33.5 | 34.6 | 35.4 | 33.1 | 34.8 | 36.4 | 33.2 | 35.0 | 36.3 | 33.8 | 35.1 | 36.2 | 33.4 | 34.8 | 36.6 |
| 3 | Max.... | 33.4 | 34.6 | 35.4 | 33.1 | 34.7 | 36.2 | 33.1 | 34.9 | 36.2 | 33.7 | 35.1 | 36.3 | 33.4 | 34.9 | 36.8 |
| | Min.... | 33.4 | 34.5 | 35.2 | 33.0 | 34.5 | 36.1 | 33.0 | 34.7 | 36.1 | 33.5 | 34.9 | 36.0 | 33.3 | 34.6 | 36.5 |
| 4 | Max.... | 33.6 | 34.8 | 35.5 | 33.4 | 34.8 | 36.4 | 33.4 | 35.0 | 36.3 | 33.9 | 35.1 | 36.4 | 33.4 | 34.8 | 36.8 |
| | Min.... | 33.6 | 34.7 | 35.4 | 33.3 | 34.7 | 36.2 | 33.3 | 34.9 | 36.1 | 33.8 | 35.0 | 36.2 | 33.4 | 34.8 | 36.6 |
| 5 | Max.... | 33.9 | 35.0 | 35.6 | 33.6 | 35.0 | 36.6 | 33.5 | 35.3 | 36.4 | 34.1 | 35.4 | 36.4 | 33.7 | 35.0 | 37.0 |
| | Min.... | 33.6 | 34.6 | 35.4 | 33.2 | 34.7 | 36.2 | 33.3 | 34.9 | 36.1 | 33.8 | 35.0 | 36.1 | 33.4 | 34.7 | 36.6 |
| 6 | Max.... | 33.8 | 34.9 | 35.5 | 33.3 | 34.8 | 36.4 | 33.4 | 35.0 | 36.3 | 33.9 | 35.1 | 36.2 | 33.4 | 34.9 | 36.8 |
| | Min.... | 33.6 | 34.7 | 35.4 | 33.2 | 34.6 | 36.2 | 33.2 | 34.9 | 36.1 | 33.9 | 35.0 | 36.1 | 33.4 | 34.8 | 36.7 |
| 7 | Max.... | 33.8 | 34.9 | 35.5 | 33.4 | 34.8 | 36.2 | 33.4 | 35.0 | 36.1 | 34.0 | 35.1 | 36.2 | 33.5 | 35.0 | 36.6 |
| | Min.... | 33.6 | 34.7 | 35.4 | 33.1 | 34.6 | 36.1 | 33.2 | 34.9 | 36.0 | 33.9 | 34.9 | 36.1 | 33.4 | 34.7 | 36.5 |
| 9 | Max.... | 34.1 | 35.2 | 35.9 | 33.5 | 35.0 | 36.5 | 33.6 | 35.2 | 36.4 | 34.3 | 35.5 | 36.5 | 33.9 | 35.2 | 37.1 |
| | Min.... | 33.8 | 34.9 | 35.5 | 33.1 | 34.7 | 36.2 | 33.3 | 35.0 | 36.1 | 33.9 | 35.1 | 36.1 | 33.5 | 34.9 | 36.7 |
| 10 | Max.... | 33.9 | 35.0 | 35.7 | 33.3 | 34.8 | 36.4 | 33.4 | 35.1 | 36.2 | 34.1 | 35.3 | 36.4 | 33.7 | 35.0 | 36.9 |
| | Min.... | 33.6 | 34.7 | 35.4 | 32.9 | 34.4 | 36.0 | 33.2 | 34.8 | 35.9 | 33.7 | 34.9 | 36.0 | 33.4 | 34.7 | 36.6 |
| 11 | Max.... | 33.8 | 34.9 | 35.6 | 33.1 | 34.7 | 36.4 | 33.4 | 35.1 | 36.3 | 34.0 | 35.2 | 36.4 | 33.7 | 35.0 | 36.9 |
| | Min.... | 33.5 | 34.7 | 35.3 | 32.7 | 34.5 | 36.1 | 33.2 | 34.8 | 36.1 | 33.8 | 35.0 | 36.0 | 33.5 | 34.8 | 36.6 |
| 12 | Max.... | 34.0 | 35.3 | 35.8 | 33.4 | 34.9 | 36.4 | 33.7 | 35.4 | 36.4 | 34.4 | 35.5 | 36.6 | 34.0 | 35.4 | 37.1 |
| | Min.... | 33.5 | 34.7 | 35.3 | 32.6 | 34.5 | 36.0 | 33.2 | 34.9 | 36.0 | 33.9 | 35.0 | 36.1 | 33.5 | 34.9 | 36.7 |
| 13 | Max.... | 33.8 | 34.9 | 35.5 | 32.6 | 34.7 | 36.2 | 33.4 | 35.2 | 36.4 | 34.1 | 35.3 | 36.4 | 33.9 | 35.2 | 37.0 |
| | Min.... | 33.4 | 34.6 | 35.2 | 32.2 | 34.3 | 36.1 | 33.2 | 34.9 | 36.1 | 33.7 | 34.9 | 36.0 | 33.6 | 34.9 | 36.6 |
| 14 | Max.... | 33.4 | 34.6 | 35.5 | 32.4 | 34.5 | 36.1 | 33.4 | 35.1 | 36.2 | 33.9 | 35.0 | 36.1 | 33.7 | 35.1 | 36.9 |
| | Min.... | 33.1 | 34.2 | 34.9 | 31.9 | 34.0 | 35.6 | 32.8 | 34.5 | 35.7 | 33.4 | 34.6 | 35.6 | 33.4 | 34.6 | 36.5 |
| 16 | Max.... | 33.3 | 34.4 | 35.1 | 32.5 | 34.3 | 35.9 | 33.0 | 34.8 | 35.9 | 33.7 | 34.9 | 36.0 | 33.5 | 34.9 | 36.7 |
| | Min.... | 33.0 | 34.2 | 34.9 | 32.2 | 34.0 | 35.5 | 32.8 | 34.4 | 35.7 | 33.4 | 34.6 | 35.5 | 33.3 | 34.6 | 36.4 |
| 17 | Max.... | 33.4 | 34.5 | 35.0 | 32.4 | 34.1 | 35.8 | 33.0 | 34.7 | 35.9 | 33.6 | 34.9 | 35.8 | 33.5 | 34.8 | 36.6 |
| | Min.... | 33.2 | 34.3 | 34.9 | 32.3 | 34.0 | 35.5 | 32.8 | 34.5 | 35.6 | 33.4 | 34.7 | 35.6 | 33.4 | 34.6 | 36.4 |
| 18 | Max.... | 33.4 | 34.4 | 35.1 | 32.5 | 34.1 | 35.7 | 33.0 | 34.6 | 35.9 | 33.6 | 34.8 | 35.8 | 33.4 | 34.7 | 36.6 |
| | Min.... | 33.2 | 34.2 | 34.7 | 32.3 | 34.0 | 35.5 | 32.8 | 34.4 | 35.5 | 33.4 | 34.6 | 35.6 | 33.2 | 34.5 | 36.4 |
| 19 | Max.... | 33.4 | 34.4 | 35.0 | 32.5 | 34.1 | 35.6 | 33.0 | 34.5 | 35.7 | 33.6 | 34.7 | 35.7 | 33.4 | 34.6 | 36.4 |
| | Min.... | 33.2 | 34.2 | 34.8 | 32.4 | 34.0 | 35.5 | 32.8 | 34.4 | 35.5 | 33.5 | 34.6 | 35.6 | 33.3 | 34.5 | 36.3 |
| 20 | Max.... | 33.6 | 34.6 | 35.4 | 33.0 | 34.5 | 36.0 | 33.4 | 34.9 | 36.0 | 34.0 | 35.1 | 36.0 | 33.6 | 34.9 | 36.6 |
| | Min.... | 33.2 | 34.2 | 34.9 | 32.4 | 34.1 | 35.5 | 32.9 | 34.4 | 35.5 | 33.5 | 34.6 | 35.5 | 33.3 | 34.5 | 36.3 |
| 21 | Max.... | 33.6 | 34.6 | 35.3 | 33.0 | 34.5 | 36.0 | 33.4 | 34.9 | 36.0 | 34.0 | 35.0 | 36.0 | 33.7 | 34.9 | 36.7 |
| | Min.... | 33.3 | 34.3 | 34.8 | 32.5 | 34.1 | 35.6 | 32.9 | 34.4 | 35.5 | 33.5 | 34.6 | 35.6 | 33.2 | 34.5 | 36.3 |
| 23 | Max.... | 33.6 | 34.7 | 35.2 | 33.1 | 34.6 | 36.0 | 33.4 | 34.8 | 35.9 | 34.0 | 35.2 | 36.0 | 33.5 | 34.9 | 36.7 |
| | Min.... | 33.4 | 34.4 | 34.9 | 32.6 | 34.2 | 35.6 | 33.0 | 34.5 | 35.5 | 33.7 | 34.7 | 35.6 | 33.4 | 34.6 | 36.4 |
| 24 | Max.... | 33.5 | 34.6 | 35.3 | 32.9 | 34.0 | 35.9 | 33.2 | 34.9 | 35.9 | 33.9 | 35.1 | 35.9 | 33.5 | 34.9 | 36.7 |
| | Min.... | 33.1 | 34.1 | 34.6 | 32.3 | 33.5 | 35.4 | 32.6 | 34.3 | 35.3 | 33.4 | 34.5 | 35.4 | 33.1 | 34.4 | 36.1 |
| 25 | Max.... | 33.4 | 34.6 | 35.2 | 32.8 | 34.4 | 35.9 | 33.2 | 34.7 | 35.9 | 33.9 | 35.0 | 35.9 | 33.5 | 34.9 | 36.6 |
| | Min.... | 33.4 | 34.6 | 35.2 | 32.8 | 34.4 | 35.9 | 33.2 | 34.7 | 35.9 | 33.9 | 35.0 | 35.9 | 33.5 | 34.9 | 36.6 |
| 26 | Max.... | 33.3 | 34.3 | 35.1 | 32.4 | 34.2 | 35.6 | 33.0 | 34.5 | 35.6 | 33.6 | 34.7 | 35.7 | 33.4 | 34.7 | 36.5 |
| | Min.... | 33.0 | 34.1 | 34.7 | 32.1 | 33.9 | 35.4 | 32.7 | 34.4 | 35.4 | 33.4 | 34.5 | 35.4 | 33.1 | 34.4 | 36.2 |
| 27 | Max.... | 33.4 | 34.4 | 34.9 | 32.7 | 34.1 | 35.5 | 33.0 | 34.5 | 35.5 | 33.6 | 34.8 | 35.7 | 33.4 | 34.8 | 36.4 |
| | Min.... | 32.9 | 33.9 | 34.5 | 32.4 | 33.8 | 35.1 | 32.5 | 34.0 | 35.1 | 33.4 | 34.4 | 35.2 | 32.9 | 34.2 | 36.0 |
| 28 | Max.... | 33.2 | 34.0 | 34.7 | 32.6 | 33.9 | 35.4 | 32.8 | 34.3 | 35.4 | 33.5 | 34.5 | 35.4 | 33.0 | 34.4 | 36.2 |
| | Min.... | 32.9 | 33.8 | 34.5 | 32.4 | 33.8 | 35.2 | 32.6 | 34.1 | 35.2 | 33.4 | 34.4 | 35.2 | 32.9 | 34.3 | 35.9 |
| Ave. | Max. | 33.59 | 34.69 | 35.36 | 32.95 | 34.52 | 36.07 | 33.27 | 34.91 | 36.06 | 33.89 | 35.07 | 36.10 | 33.55 | 34.90 | 36.74 |
| | Min. | 33.33 | 34.41 | 35.05 | 32.63 | 34.25 | 35.79 | 32.99 | 34.61 | 35.76 | 33.63 | 34.78 | 35.78 | 33.33 | 34.63 | 36.44 |
| | Range | 0.26 | 0.28 | 0.31 | 0.32 | 0.27 | 0.28 | 0.28 | 0.30 | 0.30 | 0.26 | 0.29 | 0.32 | 0.22 | 0.27 | 0.30 |

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TABLE 54.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, MARCH, 1914.

| Date— | Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 | Max.... | 33.7 | 34.5 | 35.0 | 33.1 | 34.3 | 35.5 | 33.4 | 34.6 | 35.6 | 34.0 | 35.0 | 35.9 | 33.4 | 34.8 | 36.5 |
| | Min.... | 33 4 | 34.2 | 34 7 | 32.9 | 34.1 | 35.3 | 33.0 | 34.5 | 35.5 | 33.7 | 34.6 | 35.6 | 33.2 | 34.4 | 36 2 |
| 3 | Max.... | 33.4 | 34.5 | 35.0 | 33.0 | 34.4 | 35.6 | 33.4 | 34.6 | 35.6 | 34.0 | 35.0 | 35.9 | 33.4 | 34.6 | 36.3 |
| | Min.... | 33.2 | 34.0 | 34.6 | 32.6 | 34.0 | 35 4 | 32.9 | 34.4 | 35 3 | 33.5 | 34.6 | 35.4 | 33.1 | 34.3 | 36.0 |
| 4 | Max.... | 33.4 | 34.3 | 34.7 | 32.8 | 34.2 | 35.4 | 33.1 | 34.5 | 35.5 | 33.8 | 34.7 | 35.5 | 33.4 | 34.5 | 36.2 |
| | Min.... | 33.2 | 34.1 | 34.6 | 32.7 | 34.0 | 35.3 | 33.0 | 34.4 | 35.3 | 33.7 | 34.6 | 35.5 | 33.2 | 31.3 | 36.0 |
| 5 | Max.... | 33.4 | 34.4 | 34.9 | 33.0 | 34.4 | 35.6 | 33.2 | 34.5 | 35.5 | 33.9 | 34.8 | 35.5 | 33.4 | 34.6 | 36.2 |
| | Min .... | 33.2 | 34.1 | 34.6 | 32.6 | 34.0 | 35.2 | 32.8 | 34.3 | 35.2 | 33.6 | 34.6 | 35.4 | 33.0 | 34.2 | 35.9 |
| 6 | Max.... | 33.4 | 34.4 | 34.8 | 32.9 | 33.9 | 35.0 | 33.1 | 34.5 | 35.5 | 33.9 | 34.8 | 35.5 | 33.2 | 34.4 | 36.2 |
| | Min.... | 33.3 | 34.1 | 34.6 | 32.7 | 33.8 | 34.8 | 32.9 | 34.3 | 35.2 | 33.6 | 34.5 | 35.3 | 33.1 | 34 2 | 35.9 |
| 7 | Max.... | 33.5 | 34.3 | 34.8 | 33.0 | 34.0 | 35.1 | 33.2 | 34.5 | 35.4 | 33.7 | 34.7 | 35.5 | 33.2 | 34.4 | 36.1 |
| | Min.... | 33.3 | 34.2 | 34.7 | 32.9 | 33.9 | 34.9 | 33.0 | 34.4 | 35.3 | 33.6 | 34.6 | 35.5 | 33.1 | 34.3 | 35.9 |
| 9 | Max.... | 33.5 | 34.4 | 34.9 | 33.2 | 34.4 | 35.4 | 33.1 | 34.5 | 35.5 | 33.9 | 34.8 | 35.6 | 33.3 | 34.5 | 36.0 |
| | Min.... | 33.3 | 34.2 | 34.7 | 33.0 | 34.1 | 35.3 | 33.0 | 34.4 | 35.2 | 33.7 | 34.6 | 35 4 | 33 1 | 34 1 | 35 8 |
| 10 | Max .... | 33.6 | 34.6 | 35.0 | 33.4 | 34.4 | 35.5 | 33.3 | 34.6 | 35.6 | 34.0 | 34.9 | 35.6 | 33.4 | 34.4 | 36.3 |
| | Min.... | 33.4 | 34.2 | 34.7 | 33.0 | 34.0 | 35.1 | 32.9 | 34.3 | 35.2 | 33.6 | 34.6 | 35.3 | 33.0 | 34.1 | 35 8 |
| 11 | Max .... | 33.5 | 34.4 | 35.0 | 33.4 | 34.3 | 35.5 | 33.4 | 34.5 | 35.4 | 34.0 | 34.9 | 35.5 | 33.3 | 34.4 | 36.1 |
| | Min.... | 33.3 | 34.1 | 34.6 | 33.0 | 33.9 | 35.1 | 32.9 | 34.3 | 35.1 | 33.7 | 34.5 | 35.2 | 33.0 | 34.1 | 35.8 |
| 12 | Max.... | 33.6 | 34.5 | 35.0 | 33.4 | 34.4 | 35.5 | 33.3 | 34.5 | 35.5 | 34.0 | 34.9 | 35.7 | 33.4 | 34.4 | 36.1 |
| | Min.... | 33.4 | 34.3 | 34.7 | 33.1 | 34.1 | 35.2 | 33.0 | 34.4 | 35.2 | 33.6 | 34.6 | 35.3 | 33.0 | 34.2 | 35.8 |
| 13 | Max.... | 33.6 | 34.4 | 34.9 | 33.4 | 34.4 | 35.5 | 33.2 | 34.6 | 35.5 | 33.9 | 34.8 | 35.5 | 33.4 | 34.4 | 36.0 |
| | Min.... | 33.3 | 33.9 | 34.1 | 32.7 | 33.7 | 34.9 | 32 8 | 33 9 | 34.7 | 33.4 | 34.3 | 34.9 | 33.0 | 34.0 | 35.5 |
| 14 | Max.... | 39.2 | 36.4 | 35.3 | 36.5 | 34.9 | 35.1 | 33.0 | 34.2 | 35.0 | 33.6 | 34.6 | 35.3 | 33.1 | 34.0 | 35.7 |
| | Min.... | 33.2 | 34.1 | 34.5 | 32.9 | 34.0 | 35.1 | 32.8 | 34.0 | 34.6 | 33.4 | 33.5 | 34.8 | 32.9 | 33.6 | 34.9 |
| 16 | Max.... | 43.5 | 40.6 | 38.8 | 45.6 | 41.2 | 38.0 | 40.9 | 37.0 | 35.9 | 42.5 | 37.5 | 37.0 | 33.1 | 33.9 | 35.2 |
| | Min.... | 37.1 | 38.2 | 37.5 | 36.4 | 37.7 | 37.2 | 35.7 | 35.8 | 35.5 | 36.8 | 36.5 | 36.6 | 33.0 | 33.8 | 35 0 |
| 17 | Max.... | 37.2 | 37.7 | 38.1 | 37.2 | 37.7 | 38.4 | 36.4 | 37.9 | 37.1 | 36.9 | 37.6 | 38.1 | 33.1 | 34.1 | 35.6 |
| | Min.... | 35.3 | 36.6 | 36.9 | 34.9 | 36.6 | 37.3 | 35.4 | 36.7 | 36.9 | 36.5 | 36.2 | 37.5 | 33 0 | 33.9 | 35 5 |
| 18 | Max.... | 34.9 | 36.3 | 37.0 | 34.4 | 36.3 | 37.5 | 34.9 | 36.6 | 37.1 | 35.5 | 36.1 | 37.5 | 33.3 | 34.4 | 36.1 |
| | Min .... | 34.4 | 35.7 | 36.4 | 34.1 | 35.9 | 36.9 | 34.4 | 36.2 | 36.9 | 35.0 | 35.6 | 37.1 | 33.1 | 34 4 | 36 0 |
| 19 | Max.... | 34.4 | 35.4 | 36.2 | 33.4 | 35.4 | 36.8 | 34.3 | 36.0 | 36.9 | 34.9 | 36.1 | 37.0 | 33.4 | 34.6 | 36.4 |
| | Min.... | 34.0 | 35 1 | 35 9 | 33.3 | 34.9 | 36.4 | 33.9 | 35.6 | 36.5 | 34 5 | 35 9 | 36 7 | 33.2 | 34.5 | 36.2 |
| 20 | Max.... | 34.1 | 35.2 | 35.8 | 32.9 | 34.9 | 36.4 | 34.0 | 35.6 | 36.6 | 34.5 | 35.8 | 36.5 | 33.4 | 34.8 | 36.6 |
| | Min.... | 33.9 | 34.7 | 35 4 | 32 4 | 34.3 | 35 9 | 33.6 | 35.2 | 36.1 | 34 1 | 35.2 | 36.2 | 33 1 | 34 4 | 36.4 |
| 21 | Max.... | 33.9 | 35.0 | 35.6 | 32.4 | 34.5 | 36.0 | 33.8 | 35.3 | 36.3 | 34.1 | 35.3 | 36.3 | 33.4 | 34.8 | 36.5 |
| | Min.... | 33.6 | 34 6 | 35.2 | 31.9 | 34.1 | 35 6 | 33 4 | 34.9 | 35.9 | 33.9 | 34.2 | 36.0 | 33.3 | 34.5 | 36 4 |
| 23 | Max.... | 33.6 | 34.5 | 35.1 | 32.8 | 34.3 | 35.6 | 33.4 | 34.9 | 35.7 | 33.9 | 34.4 | 35.8 | 33.2 | 34.5 | 36.3 |
| | Min.... | 33.4 | 34 4 | 34.9 | 32 6 | 34.1 | 35.4 | 33.2 | 34.6 | 35.5 | 33.6 | 33.9 | 35.5 | 33.1 | 34.4 | 36.1 |
| 24 | Max.... | 39.6 | 36.4 | 35.5 | 40.2 | 36.4 | 35.6 | 37.0 | 34.8 | 35.7 | 37.6 | 34.5 | 35.7 | 33.3 | 34.6 | 36.4 |
| | Min.... | 33.4 | 34.2 | 34.8 | 32.6 | 34.1 | 35.4 | 33 1 | 34.5 | 35.3 | 33.5 | 34.2 | 35.4 | 33.1 | 34.3 | 35.9 |
| 25 | Max.... | 43.9 | 38.9 | 37.0 | 44.2 | 38.5 | 36.3 | 40.4 | 35.7 | 35.2 | 41.2 | 36.0 | 35.4 | 32.5 | 33.5 | 35.2 |
| | Min.... | 35.0 | 35 4 | 35 6 | 34 4 | 34.9 | 35.5 | 34.3 | 35.0 | 35.1 | 34.7 | 34.4 | 35.4 | 32.4 | 33.4 | 35.0 |
| 26 | Max.... | 47.9 | 42.1 | 39.3 | 48.8 | 41.7 | 38.0 | 44.2 | 37.9 | 36.4 | 46.2 | 38.4 | 37.0 | 32.6 | 33.6 | 35.2 |
| | Min .... | 37.4 | 37 8 | 37.7 | 36.5 | 37.3 | 37.1 | 36 6 | 37.0 | 36.2 | 37.1 | 37.1 | 36.8 | 32.5 | 33.4 | 35.0 |
| 27 | Max .... | 42.5 | 43.1 | 41.9 | 42.0 | 42.8 | 40.5 | 43.1 | 41.2 | 38.7 | 43.4 | 41.6 | 39.8 | 32.7 | 33.9 | 35.4 |
| | Min.... | 40 4 | 41.0 | 40 8 | 39 9 | 40 5 | 40 0 | 40.7 | 40.7 | 37.9 | 41.1 | 40.8 | 39.1 | 32.6 | 33.8 | 35 3 |
| 28 | Max.... | 46.7 | 42.3 | 40.2 | 47.3 | 42.2 | 39.4 | 44.5 | 39.4 | 38.8 | 45.0 | 39.8 | 39.5 | 33.0 | 34.1 | 35.8 |
| | Min.... | 37 1 | 38.5 | 38.8 | 36.4 | 38 3 | 38.8 | 37.5 | 38.9 | 38.4 | 38 0 | 38.7 | 38.9 | 32.6 | 34.0 | 35.7 |
| 30 | Max.... | 43.6 | 43.7 | 42.8 | 43.2 | 43.2 | 41.7 | 44.0 | 42.6 | 40.6 | 44.4 | 42.9 | 41.5 | 39.2 | 37.3 | 37.7 |
| | Min.... | 42.3 | 42.4 | 42.1 | 42.0 | 42.1 | 41 6 | 42.6 | 42.2 | 40.3 | 43.1 | 42.3 | 41.1 | 38.9 | 36.3 | 37.1 |
| 31 | Max.... | 47.5 | 43.9 | 41.9 | 49.2 | 44.2 | 41.2 | 45.4 | 41.4 | 40.5 | 45.4 | 41.5 | 41.1 | 41.8 | 38.4 | 38.7 |
| | Min.... | 39.1 | 40.4 | 40.6 | 38.5 | 40.1 | 40.5 | 39 7 | 40.7 | 40.3 | 40.0 | 40.6 | 40.7 | 33.8 | 38.1 | 38 4 |
| Ave. | Max.. | 37.35 | 36.93 | 36.71 | 37.10 | 36.74 | 36.77 | 36.35 | 36.17 | 36.43 | 36.97 | 36.36 | 36.74 | 33.77 | 34.61 | 35.19 |
| | Min.. | 34.84 | 35.71 | 36.07 | 34.23 | 35.48 | 36.35 | 34.58 | 35.75 | 36.10 | 35.19 | 35.74 | 36.41 | 33.44 | 34.35 | 35.90 |
| | Range | 2.51 | 1.22 | 0.64 | 2.87 | 1.26 | 0.42 | 1.77 | 0.42 | 0.33 | 1.78 | 0.62 | 0.33 | 0.33 | 0.26 | 0.29 |

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TABLE 55.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, APRIL, 1914.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 45.7 | 44.0 | 42.7 | 45.9 | 43.8 | 42.2 | 44.9 | 42.6 | 41.0 | 45.3 | 42.5 | 41.7 | 43.3 | 40.0 | 39.8 |
| 1 Min.... | 43.1 | 42.9 | 42.4 | 43.0 | 42.7 | 41.8 | 43.0 | 42.3 | 40.8 | 43.3 | 42.2 | 41.4 | 42.0 | 39.5 | 39.5 |
| 2 Max.... | 41.0 | 41.8 | 42.2 | 40.8 | 41.6 | 42.1 | 41.1 | 42.4 | 41.2 | 41.4 | 42.5 | 41.9 | 41.9 | 40.9 | 40.5 |
| 2 Min.... | 39.9 | 41.1 | 41.3 | 39.2 | 40.9 | 41.4 | 40.4 | 41.5 | 41.0 | 40.6 | 41.3 | 41.4 | 41.1 | 40.8 | 40.2 |
| 3 Max.... | 42.5 | 41.3 | 40.5 | 43.1 | 41.4 | 40.7 | 41.7 | 40.6 | 40.8 | 42.2 | 40.5 | 41.1 | 40.9 | 40.8 | 40.9 |
| 3 Min.... | 36.4 | 39.0 | 39.5 | 35.7 | 38.9 | 40.2 | 37.7 | 39.9 | 40.3 | 37.8 | 39.5 | 40.4 | 39.1 | 40.4 | 40.8 |
| 4 Max.... | 36.9 | 38.3 | 39.6 | 37.4 | 38.5 | 40.3 | 36.6 | 39.9 | 40.3 | 36.9 | 39.6 | 40.6 | 38.6 | 40.5 | 41.0 |
| 4 Min.... | 35.6 | 37.6 | 38.7 | 35.0 | 37.7 | 39.5 | 35.8 | 38.6 | 39.7 | 36.0 | 38.4 | 39.6 | 34.1 | 40.0 | 40.8 |
| 6 Max.... | 34.9 | 37.1 | 38.1 | 34.5 | 37.4 | 39.0 | 35.4 | 38.0 | 38.7 | 35.5 | 37.8 | 38.6 | 37.4 | 38.8 | 40.1 |
| 6 Min.... | 34.5 | 36.3 | 37.3 | 34.1 | 36.4 | 38.1 | 34.5 | 37.1 | 38.2 | 34.7 | 36 9 | 38.1 | 36.3 | 38.4 | 39.7 |
| 7 Max.... | 37.3 | 36.6 | 36.7 | 37.7 | 36.8 | 37.8 | 35.2 | 36.7 | 37.8 | 36.6 | 36.4 | 37.7 | 35.8 | 38.1 | 39.5 |
| 7 Min.... | 34.2 | 35.7 | 36.6 | 33.7 | 35.8 | 37.5 | 33.9 | 35.9 | 37.4 | 34.4 | 36.2 | 37.4 | 35.3 | 37.6 | 39.2 |
| 8 Max.... | 34.3 | 36.3 | 37.1 | 34.4 | 36.2 | 37.8 | 34.1 | 36.4 | 37.6 | 34.7 | 36.5 | 37.7 | 35.3 | 37.3 | 39.2 |
| 8 Min.... | 33.7 | 35.7 | 36.4 | 33.2 | 35.6 | 37.3 | 33.4 | 35.8 | 37.1 | 34.2 | 36.0 | 37.1 | 34.6 | 36.9 | 38.5 |
| 9 Max.... | 34.9 | 35.2 | 36.3 | 35.4 | 35.5 | 37.1 | 33.3 | 35.7 | 37.1 | 33.7 | 35.7 | 37.2 | 34.5 | 36.8 | 38.5 |
| 9 Min.... | 33.2 | 34.8 | 35.8 | 32.9 | 35.1 | 36.8 | 33.1 | 35.3 | 36.7 | 33.4 | 35.3 | 36.7 | 34.3 | 36.3 | 38.2 |
| 10 Max.... | 39.0 | 36.9 | 36.5 | 41.3 | 37.8 | 36.8 | 35.6 | 35.3 | 36.6 | 36.3 | 35.2 | 36.6 | 34.1 | 36.2 | 38.2 |
| 10 Min.... | 33.3 | 34.7 | 35.5 | 33.2 | 34.7 | 36.5 | 33.0 | 34.9 | 36.2 | 33.2 | 34.7 | 36.1 | 33.9 | 35.8 | 37.7 |
| 11 Max.... | 42.3 | 39.4 | 38.3 | 44.3 | 40.4 | 38.2 | 39.2 | 36.8 | 36.6 | 40.1 | 37.2 | 36.8 | 35.4 | 35.8 | 37.5 |
| 11 Min.... | 36.9 | 37.4 | 37.5 | 37.3 | 37.7 | 37.7 | 35.8 | 36.3 | 36.5 | 36.6 | 36.6 | 36.6 | 33.8 | 35.4 | 37.1 |
| 13 Max .... | 50.1 | 43.5 | 40.5 | 52.3 | 44.2 | 40.0 | 46.4 | 39.1 | 38.1 | 45.7 | 39.5 | 38.8 | 38.6 | 36.7 | 37.5 |
| 13 Min.... | 35.8 | 38.4 | 38.4 | 35.8 | 38.6 | 39.0 | 36.9 | 38.1 | 37.9 | 37.2 | 38.2 | 38.4 | 36.9 | 36.6 | 37.4 |
| 14 Max.... | 55.5 | 47.4 | 43.5 | 56.9 | 47.7 | 41.9 | 52.2 | 42.0 | 39.3 | 51.0 | 42.4 | 40.0 | 43.0 | 37.6 | 38.0 |
| 14 Min.... | 38.9 | 41.1 | 40.6 | 38.2 | 41.1 | 40.4 | 39.6 | 40.1 | 39.2 | 39.7 | 40.2 | 39.6 | 38.9 | 37.4 | 37.8 |
| 15 Max.... | 54.2 | 49.0 | 45.9 | 54.6 | 48.6 | 44.1 | 52.2 | 45.1 | 41.5 | 51.2 | 45.2 | 42.4 | 45.4 | 39.8 | 39.0 |
| 15 Min.... | 45.4 | 45.5 | 44.2 | 45.0 | 45.1 | 43.1 | 45.7 | 44.0 | 41.0 | 45.3 | 43.8 | 41.9 | 43.0 | 39.0 | 38.6 |
| 16 Max.... | 55.6 | 49.8 | 46.8 | 56.2 | 49.6 | 45.0 | 53.8 | 46.2 | 43.0 | 52.6 | 46.4 | 43.8 | 47.0 | 41.5 | 40.4 |
| 16 Min.... | 45.3 | 46.2 | 45.1 | 44.5 | 45.6 | 44.1 | 46.0 | 45.1 | 42.7 | 45.7 | 45.0 | 43.6 | 44.8 | 41.0 | 39 9 |
| 17 Max.... | 61.3 | 53.1 | 48.9 | 62.2 | 53.0 | 46.5 | 57.9 | 48.0 | 44.0 | 56.5 | 47.5 | 44.9 | 50.2 | 43.1 | 41.6 |
| 17 Min.... | 46.0 | 47.4 | 46.2 | 44.9 | 46.8 | 4.51 | 47.3 | 46.4 | 43.9 | 46 8 | 45.8 | 44 7 | 46.5 | 42.7 | 41 3 |
| 18 Max.... | 65.0 | 56.5 | 51.9 | 65.4 | 55.9 | 49.0 | 61.6 | 51.2 | 45.9 | 60.4 | 50.9 | 47.0 | 53.9 | 45.2 | 43.1 |
| 18 Min.... | 53.0 | 51.5 | 49 7 | 52.8 | 51.0 | 47.9 | 52.8 | 49.6 | 45.3 | 52 2 | 49.5 | 46 5 | 50.4 | 44.4 | 42 5 |
| 20 Max.... | 45.9 | 48.6 | 49.5 | 45.5 | 47.7 | 48.7 | 47.4 | 50.7 | 48.4 | 47.3 | 50.1 | 49.3 | 49.6 | 48.4 | 48.5 |
| 20 Min.... | 44.1 | 46.6 | 47.1 | 42.9 | 45.6 | 46.6 | 45.8 | 48.1 | 47.5 | 45.8 | 47.5 | 47 9 | 48.0 | 48.0 | 46 0 |
| 21 Max.... | 53.7 | 48.4 | 46.4 | 55.3 | 48.9 | 45.7 | 51.4 | 46.6 | 46.6 | 50.7 | 46.0 | 46.7 | 48.4 | 47.5 | 46.8 |
| 21 Min.... | 41.5 | 44.3 | 44.8 | 40.4 | 43.9 | 45.0 | 43.3 | 45.6 | 45.5 | 43.1 | 44.9 | 45 6 | 45.9 | 46.6 | 46 4 |
| 22 Max.... | 58.4 | 52.3 | 49.2 | 59.5 | 52.4 | 47.9 | 55.6 | 48.6 | 45.9 | 54.9 | 48.6 | 46.5 | 51.4 | 46.9 | 46.3 |
| 22 Min.... | 48.8 | 48.6 | 47.8 | 48.3 | 48.4 | 47.1 | 49.2 | 47 9 | 45.8 | 48.8 | 47.5 | 46.3 | 49.0 | 46.8 | 46 3 |
| 23 Max.... | 57.5 | 52.8 | 49.9 | 58.1 | 52.6 | 48.7 | 55.4 | 49.8 | 47.0 | 54.3 | 49.2 | 47.7 | 51.5 | 47.5 | 46.5 |
| 23 Min.... | 46.4 | 48.8 | 48.2 | 45.5 | 48 2 | 47.7 | 48 3 | 48 6 | 46.9 | 47.4 | 48.0 | 47.3 | 48.9 | 47.4 | 46 3 |
| 24 Max.... | 54.6 | 51.2 | 49.8 | 54.8 | 50.9 | 48.9 | 53.1 | 50.0 | 47.5 | 52.5 | 49.4 | 48.0 | 50.9 | 47.8 | 46.8 |
| 24 Min.... | 49.0 | 49.5 | 49.0 | 48.4 | 49.0 | 48 2 | 49 9 | 49.3 | 47.2 | 48.9 | 48 6 | 47.7 | 49.6 | 47.6 | 46.7 |
| 25 Max.... | 58.9 | 54.4 | 51.7 | 60.6 | 55.0 | 50.3 | 57.6 | 51.1 | 47.9 | 57.6 | 51.3 | 48.4 | 54.3 | 48.3 | 47.2 |
| 25 Min.... | 51.9 | 50.6 | 49.9 | 51.8 | 50.3 | 48.7 | 51.4 | 50.0 | 47.6 | 51.1 | 49.7 | 48 1 | 51.0 | 47.9 | 46 9 |
| 27 Max.... | 65.4 | 58.7 | 54.5 | 67.1 | 59.9 | 52.8 | 62.8 | 53.6 | 49.4 | 62.5 | 53.9 | 50.5 | 57.5 | 50.6 | 48.9 |
| 27 Min.... | 51.3 | 52.6 | 51.7 | 51.0 | 52.8 | 51.0 | 52.3 | 51.9 | 49.3 | 52.0 | 51.4 | 50.2 | 53.8 | 50.5 | 48 5 |
| 28 Max.... | 65.9 | 60.6 | 56.8 | 69.4 | 62.0 | 54.9 | 64.2 | 56.4 | 51.4 | 63.9 | 56.7 | 52.6 | 61.2 | 52.8 | 50.2 |
| 28 Min.... | 56.9 | 56.5 | 54.9 | 56.8 | 56.4 | 53.7 | 57.3 | 55.2 | 51.1 | 56.9 | 54.8 | 52 1 | 57.7 | 52.1 | 49 5 |
| 29 Max.... | 59.0 | 58.4 | 56.9 | 59.0 | 58.6 | 55.6 | 59.9 | 57.3 | 52.8 | 59.9 | 57.3 | 53.9 | 60.6 | 54.7 | 51.9 |
| 29 Min.... | 58.0 | 57.2 | 56.1 | 58.4 | 57.2 | 54.8 | 58.7 | 56.7 | 52.5 | 58.5 | 56.5 | 53.8 | 59.6 | 54.1 | 51.0 |
| 30 Max.... | 56.9 | 54.7 | 53.2 | 59.2 | 55.8 | 53.1 | 56.5 | 54.5 | 52.9 | 55.1 | 53.9 | 53.6 | 55.8 | 55.0 | 52.6 |
| 30 Min.... | 47.5 | 51.0 | 51.8 | 46.3 | 50.8 | 51.8 | 50.7 | 53.2 | 51.7 | 50.1 | 52.3 | 52.1 | 53.9 | 54.0 | 52.6 |
| Ave. Max.. | 50.26 | 47.17 | 45.52 | 51.19 | 47.39 | 44.81 | 48.66 | 45.18 | 43.43 | 48.42 | 45.08 | 44.00 | 46.02 | 43.41 | 43.02 |
| Ave. Min.. | 43.10 | 44.27 | 44.10 | 42.63 | 44.09 | 43.88 | 43.68 | 44.13 | 43.04 | 43.49 | 43.88 | 43.48 | 43.94 | 42.97 | 42.67 |
| Ave. Range | 7.16 | 2.90 | 1.42 | 8.56 | 3.30 | 0.93 | 4.98 | 1.05 | 0.39 | 4.93 | 1.20 | 0.52 | 2.08 | 0.44 | 0.35 |

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TABLE 56.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, MAY, 1914.

| Date— | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 54.8 | 52.2 | 51.6 | 55.8 | 52.5 | 52.1 | 54.2 | 52.6 | 51.6 | 54.0 | 51.5 | 51.9 | 53.6 | 53.2 | 52.7 |
| 1 Min. | 46.7 | 49.6 | 50.1 | 45.3 | 49.4 | 50.5 | 48.6 | 51.2 | 50.5 | 47.8 | 49.9 | 50.6 | 50.8 | 52.5 | 52.1 |
| 2 Max. | 60.7 | 54.0 | 51.4 | 62.8 | 54.4 | 50.6 | 58.3 | 51.3 | 50.4 | 58.4 | 50.5 | 50.7 | 55.3 | 52.2 | 51.9 |
| 2 Min. | 46.5 | 49.5 | 49.5 | 45.0 | 49.0 | 49.6 | 48.0 | 50.1 | 49.6 | 47.9 | 49.2 | 49.9 | 50.5 | 51.4 | 51.3 |
| 4 Max. | 62.0 | 57.3 | 54.7 | 62.8 | 57.6 | 53.4 | 60.5 | 54.6 | 51.3 | 60.9 | 54.4 | 52.5 | 58.5 | 53.2 | 51.4 |
| 4 Min. | 54.2 | 54.4 | 53.4 | 53.8 | 54.2 | 52.5 | 55.0 | 53.9 | 51.1 | 55.1 | 53.0 | 52.2 | 56.5 | 53.0 | 51.3 |
| 5 Max. | 60.8 | 56.9 | 55.4 | 61.4 | 56.8 | 54.2 | 59.6 | 55.9 | 52.4 | 60.0 | 55.2 | 53.6 | 58.5 | 54.2 | 52.3 |
| 5 Min. | 57.4 | 56.1 | 55.1 | 56.9 | 55.7 | 53.9 | 57.5 | 55.5 | 52.1 | 57.8 | 54.8 | 53.5 | 57.9 | 53.9 | 51.9 |
| 6 Max. | 59.6 | 57.1 | 55.1 | 61.4 | 57.5 | 54.1 | 59.6 | 55.6 | 52.9 | 60.0 | 54.7 | 54.1 | 58.6 | 54.8 | 52.9 |
| 6 Min. | 53.4 | 54.8 | 54.1 | 52.1 | 54.2 | 53.3 | 54.8 | 54.8 | 52.6 | 54.8 | 53.9 | 53.5 | 56.5 | 54.5 | 52.8 |
| 7 Max. | 55.8 | 54.3 | 53.9 | 56.8 | 54.5 | 53.6 | 55.2 | 54.8 | 52.9 | 55.9 | 53.8 | 53.9 | 55.9 | 54.9 | 53.4 |
| 7 Min. | 50.0 | 53.0 | 52.9 | 48.8 | 52.7 | 52.6 | 51.8 | 53.6 | 52.3 | 52.1 | 52.8 | 53.2 | 54.4 | 54.4 | 53.2 |
| 8 Max. | 54.6 | 53.4 | 52.7 | 54.9 | 53.4 | 52.4 | 54.4 | 53.3 | 52.1 | 54.9 | 52.5 | 53.0 | 54.9 | 54.2 | 53.3 |
| 8 Min. | 50.6 | 51.9 | 52.0 | 49.6 | 51.5 | 52.0 | 51.7 | 52.8 | 51.5 | 52.1 | 51.9 | 52.4 | 53.5 | 53.7 | 53.1 |
| 9 Max. | 62.6 | 58.1 | 53.0 | 65.0 | 56.9 | 52.1 | 60.1 | 52.5 | 51.1 | 61.1 | 52.9 | 52.2 | 57.1 | 53.6 | 53.0 |
| 9 Min. | 47.2 | 50.3 | 50.8 | 45.7 | 49.8 | 50.6 | 48.6 | 51.3 | 50.9 | 48.8 | 51.1 | 51.5 | 52.3 | 52.9 | 52 6 |
| 11 Max. | 55.6 | 57.7 | 57.3 | 54.4 | 57.6 | 56.3 | 57.5 | 57.5 | 53.9 | 57.6 | 57.9 | 55.2 | 59.5 | 55.4 | 53.4 |
| 11 Min. | 50.6 | 53.4 | 54.3 | 49.4 | 52.8 | 54.0 | 52.0 | 55.1 | 53.4 | 51.8 | 54.8 | 54.9 | 55.3 | 55.2 | 52.9 |
| 12 Max. | 47.3 | 49.0 | 50.9 | 46.5 | 48.4 | 51.3 | 47.3 | 51.4 | 52.6 | 47.3 | 50.5 | 52.7 | 49.1 | 54.0 | 54.3 |
| 12 Min. | 46.0 | 48.4 | 49.5 | 45.0 | 48.0 | 49.9 | 46.8 | 49.9 | 51.1 | 46 4 | 49.1 | 50.9 | 48.0 | 52.1 | 53.8 |
| 13 Max. | 53.4 | 50.3 | 49.3 | 54.6 | 50.5 | 49.2 | 51.8 | 49.0 | 50.0 | 52.2 | 48.7 | 49.8 | 49.4 | 51.0 | 52.8 |
| 13 Min. | 44.9 | 47.3 | 48.2 | 44.1 | 47.0 | 48.8 | 45.6 | 48.4 | 49.1 | 45.5 | 47.9 | 49.0 | 47.1 | 50.0 | 51.6 |
| 14 Max. | 54.8 | 52.4 | 50.5 | 57.0 | 53.4 | 50.0 | 53.9 | 49.6 | 49.3 | 54.6 | 50.0 | 49.7 | 51.9 | 50.2 | 51.3 |
| 14 Min. | 44.0 | 47.5 | 48.4 | 42.4 | 47.3 | 48.8 | 45.2 | 48.4 | 48.7 | 45.2 | 48.0 | 49.1 | 47.8 | 49.6 | 50.6 |
| 15 Max. | 58.6 | 53.4 | 50.9 | 62.1 | 54.2 | 50.4 | 56.5 | 50.1 | 49.4 | 57.8 | 50.8 | 50.0 | 53.2 | 50.1 | 50.5 |
| 15 Min. | 45.1 | 48.8 | 49.1 | 43.9 | 48.7 | 49.4 | 46.6 | 49.0 | 48.9 | 46 8 | 48.9 | 49 6 | 48.9 | 49.7 | 50.2 |
| 16 Max. | 61.8 | 54.7 | 52.0 | 64.4 | 55.3 | 51.4 | 58.6 | 51.4 | 49.8 | 59.8 | 52.0 | 50.8 | 54.3 | 50.6 | 50.3 |
| 16 Min. | 47.5 | 50.6 | 50.5 | 46.7 | 50.6 | 50.5 | 48.9 | 50.3 | 49.5 | 49.4 | 50.9 | 50.5 | 51.3 | 50.3 | 50.1 |
| 18 Max. | 68.1 | 60.3 | 56.4 | 69.8 | 60.7 | 54.4 | 65.7 | 55.6 | 51.9 | 66.0 | 56.6 | 53.4 | 60.7 | 52.7 | 51.4 |
| 18 Min. | 53.2 | 55.0 | 53.9 | 52.3 | 54.5 | 53.3 | 54.4 | 54.1 | 51.8 | 54.6 | 54.4 | 53.1 | 55.2 | 52.6 | 51.1 |
| 19 Max. | 71.1 | 62.8 | 58.4 | 73.3 | 62.9 | 56.2 | 68.8 | 58.1 | 53.5 | 68.9 | 58.7 | 55.0 | 64.1 | 54.6 | 52.5 |
| 19 Min. | 56.0 | 57.5 | 56.4 | 55.0 | 57.1 | 55.1 | 57.3 | 56 6 | 53.3 | 57.3 | 56.6 | 54.8 | 58.2 | 54.3 | 52.1 |
| 20 Max. | 72.2 | 64.4 | 60.4 | 73.4 | 64.4 | 58.1 | 70.3 | 60.3 | 55.1 | 70.1 | 60.5 | 56.9 | 66.4 | 56.8 | 53.9 |
| 20 Min. | 59 2 | 60 0 | 58.4 | 58.3 | 59.6 | 56.9 | 60.3 | 59.0 | 55.1 | 60.3 | 59.1 | 56.8 | 61.6 | 56.4 | 53 4 |
| 21 Max. | 72.9 | 65.3 | 61.7 | 73.6 | 64.6 | 59.3 | 71.1 | 61.9 | 56.9 | 70.8 | 62.2 | 58.5 | 68.0 | 58.8 | 55.7 |
| 21 Min. | 61 1 | 61 6 | 60.1 | 59.9 | 61.1 | 58.4 | 62.0 | 60.9 | 56.7 | 61.9 | 60.6 | 58.3 | 63 6 | 58.7 | 55 1 |
| 22 Max. | 70.8 | 65.6 | 62.5 | 71.6 | 65.5 | 60.6 | 69.4 | 63.1 | 58.3 | 70.0 | 63.2 | 59.8 | 68.2 | 60.9 | 57.5 |
| 22 Min. | 64.3 | 63.1 | 61 8 | 63 8 | 62 5 | 60.0 | 65.1 | 62.5 | 57.9 | 65.0 | 62.5 | 59 8 | 65.7 | 60 5 | 56 7 |
| 23 Max. | 70.1 | 64.1 | 61.3 | 71.5 | 64.2 | 60.0 | 68.8 | 62.4 | 58.9 | 68.9 | 62.1 | 60.5 | 66.8 | 61.9 | 58.8 |
| 23 Min. | 57.4 | 60.4 | 59.9 | 55.4 | 59.7 | 58.7 | 59.6 | 61.1 | 58.2 | 59.7 | 60.7 | 59.6 | 63.0 | 61.4 | 58 3 |
| 25 Max. | 73.7 | 65.3 | 61.4 | 76.1 | 66.1 | 59.6 | 71.4 | 61.2 | 57.7 | 71.3 | 61.7 | 58.5 | 67.9 | 60.7 | 59.0 |
| 25 Min. | 58.8 | 58.5 | 58.4 | 58.1 | 58 2 | 57.7 | 59.3 | 59.2 | 57.2 | 59.3 | 59.2 | 58.2 | 61.4 | 60.4 | 58.9 |
| 26 Max. | 77.9 | 69.3 | 64.9 | 79.9 | 69.0 | 62.8 | 75.8 | 64.8 | 59.1 | 75.8 | 65.4 | 61.2 | 72.6 | 62.4 | 59.4 |
| 26 Min. | 66.0 | 64.9 | 63.1 | 65.8 | 64.1 | 61.5 | 66.7 | 63.4 | 58.4 | 66.7 | 63.8 | 60.4 | 67.7 | 61.8 | 59.1 |
| 27 Max. | 73.6 | 68.8 | 66.1 | 73.9 | 68.9 | 64.6 | 72.8 | 67.7 | 61.9 | 72.8 | 67.3 | 63.4 | 71.5 | 64.8 | 60.9 |
| 27 Min. | 69.0 | 67.0 | 65.7 | 68.4 | 66.9 | 64.2 | 69.7 | 66 7 | 61.9 | 69.9 | 66.7 | 63.3 | 70.1 | 64.1 | 60.0 |
| 28 Max. | 70.9 | 67.3 | 65.5 | 74.5 | 68.1 | 64.1 | 70.6 | 66.6 | 62.4 | 70.9 | 66.4 | 63.8 | 70.2 | 65.5 | 62.4 |
| 28 Min. | 66.1 | 65.6 | 64.6 | 65.3 | 65.1 | 63 4 | 67.5 | 65.9 | 62.1 | 67.3 | 65.8 | 63.4 | 68.7 | 65.4 | 61 9 |
| 29 Max. | 76.9 | 70.2 | 66.2 | 76.8 | 70.3 | 64.2 | 76.6 | 66.4 | 62.2 | 76.8 | 67.1 | 63.6 | 73.4 | 65.6 | 62.8 |
| 29 Min. | 63.3 | 64.1 | 63.9 | 63.5 | 64.7 | 62.9 | 64.8 | 64 8 | 61.9 | 64.9 | 64.8 | 63.1 | 67.7 | 65.3 | 62 7 |
| 30 Max. | 74.2 | 69.2 | 66.5 | 78.4 | 69.3 | 64.7 | 73.8 | 67.1 | 63.0 | 74.2 | 67.0 | 64.7 | 72.8 | 66.7 | 63.6 |
| 30 Min. | 65.0 | 66.2 | 65.1 | 63.5 | 65.3 | 63.8 | 66.9 | 66.5 | 62.9 | 66.7 | 66.1 | 64.2 | 69.4 | 66.5 | 63 3 |
| Ave. Max. | 64.42 | 59.67 | 57.31 | 65.80 | 59.88 | 56.14 | 63.18 | 57.49 | 54.64 | 63.50 | 57.45 | 55.75 | 61.25 | 56.68 | 55.05 |
| Ave. Min | 54.75 | 56.13 | 55.74 | 53.77 | 55.76 | 55.09 | 55.95 | 56.35 | 54.18 | 55.97 | 56.02 | 55.23 | 57.81 | 56.18 | 54.62 |
| Ave. Range | 9.67 | 3.54 | 1.57 | 12.03 | 4.12 | 1.05 | 7.23 | 1.14 | 0.46 | 7.53 | 1.43 | 0.52 | 3.44 | 0.50 | 0.43 |

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TABLE 57.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, JUNE, 1914.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 78.0 | 71.0 | 67.2 | 79.2 | 70.7 | 65.4 | 76.9 | 67.5 | 63.4 | 76.5 | 67.9 | 65.0 | 74.1 | 66.9 | 64.2 |
| 1 Min.... | 65.5 | 66.6 | 65.4 | 64.6 | 66.0 | 64.3 | 67.1 | 66.4 | 63.1 | 67.3 | 66.2 | 64.7 | 69.1 | 66.6 | 64.1 |
| 2 Max.... | 77.1 | 70.0 | 66.6 | 78.3 | 70.1 | 65.4 | 75.3 | 67.7 | 64.1 | 74.7 | 67.4 | 65.6 | 73.0 | 67.4 | 64.6 |
| 2 Min.... | 62.4 | 65.6 | 64.9 | 59.9 | 64.7 | 63.8 | 64.6 | 66.0 | 63.4 | 64.3 | 65.6 | 64.6 | 67.8 | 66.7 | 64.4 |
| 3 Max.... | 71.3 | 68.3 | 66.5 | 71.4 | 68.2 | 65.4 | 71.2 | 67.5 | 63.9 | 70.8 | 66.9 | 65.4 | 71.1 | 67.3 | 64.7 |
| 3 Min.... | 64.1 | 66.1 | 65.3 | 62.7 | 65.4 | 64.3 | 65.9 | 66.4 | 63.6 | 65.4 | 65.7 | 64.7 | 68.4 | 66.9 | 64.6 |
| 4 Max.... | 66.7 | 65.9 | 65.6 | 66.4 | 65.4 | 64.6 | 66.9 | 66.7 | 63.9 | 66.8 | 66.3 | 64.9 | 68.7 | 66.8 | 64.9 |
| 4 Min.... | 65.0 | 65.4 | 65.0 | 64.2 | 65.1 | 64.1 | 66.4 | 66.1 | 63.6 | 66.3 | 65.7 | 64.6 | 68.1 | 66.6 | 64.7 |
| 5 Max.... | 66.1 | 63.8 | 62.6 | 68.0 | 64.2 | 62.5 | 66.0 | 64.1 | 63.0 | 66.4 | 63.5 | 63.8 | 66.4 | 66.2 | 64.8 |
| 5 Min.... | 58.3 | 61.4 | 61.8 | 56.7 | 60.8 | 61.5 | 60.5 | 63.0 | 62.0 | 60.0 | 62.3 | 62.7 | 64.0 | 65.1 | 64.6 |
| 6 Max.... | 72.8 | 65.5 | 62.7 | 75.0 | 66.6 | 62.1 | 70.2 | 62.6 | 61.7 | 70.7 | 63.1 | 62.4 | 67.4 | 64.8 | 64.1 |
| 6 Min.... | 56.9 | 59.9 | 60.6 | 55.7 | 59.9 | 60.8 | 58.6 | 61.5 | 60.8 | 58.8 | 61.4 | 61.6 | 62.9 | 63.9 | 63.5 |
| 8 Max.... | 85.7 | 75.9 | 70.8 | 86.2 | 76.6 | 68.0 | 83.4 | 70.0 | 63.8 | 82.9 | 70.9 | 65.7 | 80.1 | 66.9 | 63.8 |
| 8 Min.... | 70.6 | 69.5 | 68.2 | 70.6 | 69.6 | 66.3 | 71.1 | 68.0 | 63.1 | 71.1 | 68.1 | 65.1 | 72.4 | 66.2 | 63.2 |
| 9 Max.... | 86.7 | 78.0 | 73.4 | 87.1 | 77.3 | 70.2 | 84.9 | 73.0 | 66.3 | 84.1 | 73.3 | 68.4 | 82.8 | 70.0 | 65.6 |
| 9 Min.... | 74.1 | 73.2 | 71.2 | 73.5 | 72.8 | 68.9 | 74.7 | 71.5 | 65.6 | 74.4 | 71.2 | 67.9 | 76.9 | 69.4 | 64.7 |
| 10 Max.... | 87.4 | 79.2 | 74.9 | 87.0 | 78.1 | 71.4 | 85.9 | 74.9 | 68.1 | 85.1 | 74.4 | 70.2 | 84.8 | 72.5 | 67.8 |
| 10 Min.... | 75.1 | 74.9 | 73.1 | 74.1 | 73.4 | 70.3 | 76.5 | 73.6 | 67.9 | 76.0 | 72.7 | 70.0 | 78.9 | 72.1 | 66.7 |
| 11 Max.... | 81.9 | 76.0 | 74.1 | 81.5 | 74.0 | 71.6 | 80.8 | 75.1 | 69.4 | 80.3 | 73.9 | 71.3 | 80.5 | 74.1 | 69.3 |
| 11 Min.... | 73.8 | 73.7 | 72.9 | 72.2 | 71.5 | 70.5 | 75.1 | 73.9 | 69.2 | 74.5 | 72.4 | 70.6 | 77.7 | 73.8 | 68.8 |
| 12 Max.... | 81.5 | 75.3 | 72.5 | 80.6 | 74.3 | 70.5 | 80.6 | 73.6 | 69.2 | 80.0 | 72.1 | 70.8 | 80.6 | 74.1 | 70.0 |
| 12 Min.... | 70.1 | 71.4 | 71.2 | 68.9 | 70.3 | 69.4 | 71.9 | 72.3 | 68.6 | 71.4 | 70.6 | 69.9 | 75.8 | 73.4 | 69.9 |
| 13 Max.... | 78.9 | 74.6 | 72.0 | 78.1 | 72.8 | 70.0 | 78.8 | 73.0 | 69.5 | 78.0 | 71.4 | 70.3 | 79.6 | 73.9 | 70.1 |
| 13 Min.... | 70.5 | 71.7 | 70.9 | 68.9 | 69.8 | 69.1 | 71.8 | 71.8 | 68.7 | 71.3 | 70.2 | 69.6 | 75.9 | 73.4 | 70.1 |
| 15 Max.... | 78.2 | 73.6 | 71.1 | 77.4 | 72.7 | 69.4 | 77.9 | 71.8 | 68.4 | 77.4 | 70.6 | 69.6 | 78.4 | 73.1 | 70.0 |
| 15 Min.... | 68.7 | 70.4 | 69.8 | 67.2 | 69.7 | 68.5 | 70.1 | 70.7 | 67.9 | 69.8 | 69.3 | 68.9 | 74.4 | 72.4 | 69.9 |
| 16 Max.... | 77.4 | 71.2 | 69.1 | 76.1 | 70.1 | 68.5 | 76.1 | 70.5 | 68.1 | 75.5 | 68.9 | 69.3 | 75.9 | 72.5 | 69.9 |
| 16 Min.... | 63.4 | 67.0 | 67.6 | 62.0 | 66.2 | 66.9 | 65.4 | 68.7 | 66.9 | 65.0 | 66.9 | 67.8 | 70.6 | 71.1 | 69.4 |
| 17 Max.... | 79.8 | 72.3 | 69.2 | 78.3 | 71.2 | 67.7 | 77.8 | 69.5 | 67.0 | 77.1 | 68.2 | 68.1 | 76.6 | 71.3 | 69.2 |
| 17 Min.... | 64.3 | 67.4 | 67.5 | 62.6 | 66.3 | 66.5 | 65.9 | 68.0 | 66.3 | 65.4 | 66.3 | 67.1 | 70.4 | 70.4 | 68.8 |
| 18 Max.... | 80.9 | 73.5 | 70.2 | 79.1 | 72.2 | 68.3 | 78.9 | 70.1 | 66.9 | 78.3 | 69.3 | 68.1 | 77.6 | 71.1 | 68.6 |
| 18 Min.... | 66.6 | 68.9 | 68.5 | 65.0 | 67.8 | 67.1 | 67.9 | 68.8 | 66.5 | 67.1 | 67.2 | 67.5 | 71.7 | 70.5 | 68.5 |
| 19 Max.... | 70.1 | 71.1 | 70.6 | 69.0 | 70.3 | 69.1 | 71.1 | 71.1 | 67.4 | 70.4 | 69.9 | 68.7 | 74.4 | 71.4 | 68.7 |
| 19 Min.... | 66.7 | 67.9 | 68.0 | 66.0 | 67.1 | 67.3 | 68.4 | 68.9 | 67.0 | 67.9 | 67.8 | 68.0 | 71.2 | 70.8 | 68.6 |
| 20 Max.... | 72.7 | 67.5 | 65.5 | 73.2 | 67.3 | 64.9 | 71.3 | 66.4 | 66.3 | 71.2 | 65.0 | 66.8 | 70.6 | 69.8 | 68.6 |
| 20 Min.... | 57.7 | 62.6 | 63.8 | 55.3 | 61.6 | 63.8 | 59.8 | 65.0 | 64.8 | 59.6 | 63.5 | 65.2 | 65.2 | 68.3 | 67.9 |
| 22 Max.... | 75.0 | 68.4 | 66.1 | 75.4 | 68.0 | 65.2 | 72.6 | 66.1 | 64.3 | 73.1 | 65.6 | 65.1 | 69.8 | 67.1 | 66.6 |
| 22 Min.... | 64.7 | 64.9 | 64.8 | 64.0 | 64.6 | 64.6 | 65.3 | 65.4 | 63.9 | 65.2 | 64.6 | 64.7 | 66.9 | 66.7 | 66.3 |
| 23 Max.... | 78.9 | 72.8 | 69.5 | 82.6 | 72.3 | 68.0 | 77.3 | 69.1 | 64.9 | 77.9 | 69.7 | 66.4 | 74.8 | 67.7 | 66.2 |
| 23 Min.... | 69.7 | 68.5 | 67.5 | 68.8 | 67.4 | 66.8 | 69.9 | 67.9 | 64.6 | 69.8 | 67.1 | 65.9 | 70.5 | 66.4 | 66.1 |
| 24 Max.... | 82.9 | 75.4 | 71.6 | 84.9 | 76.3 | 70.1 | 80.7 | 71.3 | 66.5 | 80.9 | 72.1 | 68.2 | 77.8 | 69.7 | 67.0 |
| 24 Min.... | 71.1 | 70.9 | 69.8 | 71.1 | 71.1 | 68.9 | 71.9 | 70.0 | 66.2 | 72.1 | 70.4 | 67.9 | 73.1 | 69.2 | 66.7 |
| 25 Max.... | 83.6 | 77.4 | 73.4 | 85.8 | 78.0 | 71.2 | 83.4 | 73.2 | 67.9 | 83.1 | 73.5 | 69.7 | 80.5 | 71.2 | 68.3 |
| 25 Min.... | 72.0 | 72.4 | 71.2 | 71.6 | 72.4 | 70.0 | 73.3 | 71.8 | 67.8 | 73.3 | 71.6 | 69.6 | 74.6 | 71.0 | 67.8 |
| 26 Max.... | 73.8 | 74.0 | 73.5 | 75.9 | 73.5 | 72.0 | 75.4 | 74.1 | 69.3 | 75.2 | 74.1 | 71.1 | 76.5 | 72.8 | 69.6 |
| 26 Min.... | 69.3 | 73.2 | 72.2 | 66.2 | 72.7 | 70.7 | 74.2 | 73.0 | 69.2 | 73.9 | 72.9 | 70.6 | 75.5 | 72.7 | 69.0 |
| 27 Max.... | 69.1 | 70.0 | 69.9 | 67.9 | 69.9 | 69.3 | 72.9 | 71.3 | 69.3 | 73.1 | 70.7 | 70.4 | 71.8 | 72.6 | 70.2 |
| 27 Min.... | 64.2 | 68.2 | 68.8 | 67.2 | 68.3 | 68.0 | 68.5 | 70.0 | 68.2 | 68.1 | 69.6 | 69.8 | 69.9 | 71.5 | 70.0 |
| 29 Max.... | 65.8 | 64.6 | 64.7 | 69.4 | 65.1 | 65.1 | 66.7 | 66.2 | 66.2 | 67.1 | 65.4 | 66.6 | 66.9 | 69.4 | 69.2 |
| 29 Min.... | 58.4 | 62.4 | 63.8 | 53.4 | 62.1 | 64.2 | 61.9 | 64.8 | 64.8 | 61.6 | 64.3 | 65.1 | 64.6 | 67.9 | 68.4 |
| 30 Max.... | 75.4 | 68.9 | 65.7 | 73.1 | 70.0 | 65.1 | 73.8 | 65.4 | 64.4 | 73.8 | 65.6 | 65.0 | 71.3 | 67.5 | 67.5 |
| 30 Min.... | 57.7 | 62.3 | 63 2 | 58.1 | 62.3 | 63 6 | 61 1 | 63.9 | 63.7 | 61.2 | 63 5 | 64.3 | 65 3 | 66.7 | 66.8 |
| Ave. Max.. | 76.83 | 71.01 | 69.19 | 77.19 | 71.36 | 67.73 | 76.03 | 69.68 | 66.28 | 75.78 | 69.22 | 67.57 | 75.08 | 69.93 | 67.44 |
| Ave. Min.. | 66.19 | 67.94 | 67.58 | 65.02 | 67.27 | 66.55 | 67.99 | 68.36 | 65.67 | 67.72 | 67.58 | 66.67 | 70.84 | 69.22 | 67.06 |
| Ave. Range | 10.64 | 3.07 | 1.61 | 12.17 | 4.09 | 1.18 | 8.04 | 1.32 | 0.61 | 8.06 | 1.64 | 0.80 | 4.24 | 0.71 | 0.38 |

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TABLE 58.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, JULY, 1914

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max. | 66.8 | 66.7 | 66.7 | 66.9 | 66.8 | 66.5 | 66.9 | 67.0 | 64.6 | 66.9 | 67.0 | 65.7 | 69.2 | 67.5 | 66.5 |
| 1 Min. | 64.5 | 65.4 | 65 4 | 63.1 | 65.3 | 65.1 | 65.2 | 65.9 | 64.4 | 65.1 | 65.7 | 65.3 | 67.6 | 67.1 | 66.3 |
| 2 Max. | 69.5 | 66.3 | 65.0 | 71.4 | 66.9 | 64.5 | 69.3 | 65.1 | 64.3 | 69.9 | 65.1 | 65.1 | 68.9 | 66.7 | 66.2 |
| 2 Min. | 61.4 | 63.3 | 63 9 | 60.2 | 62.9 | 63.8 | 62.6 | 64.6 | 63.6 | 62.5 | 64.0 | 64.4 | 65.4 | 66.1 | 65 9 |
| 3 Max. | 77.8 | 70.4 | 66.8 | 79.9 | 71.4 | 65.9 | 75.8 | 66.4 | 63.9 | 76.2 | 67.0 | 65.0 | 73.6 | 66.5 | 65.8 |
| 3 Min. | 60.9 | 63.6 | 64 1 | 60.0 | 63.5 | 63.9 | 62.9 | 64.7 | 63.6 | 63.1 | 64.5 | 64.6 | 66.5 | 66.1 | 65 5 |
| 4 Max. | 72.3 | 71.0 | 68.3 | 72.7 | 71.4 | 67.1 | 75.7 | 68.2 | 65.0 | 75.6 | 68.6 | 66.3 | 73.8 | 67.6 | 65.9 |
| 4 Min. | 66.6 | 67.9 | 67.8 | 60.2 | 67.6 | 66.4 | 67.9 | 67.4 | 64.7 | 67.9 | 67.4 | 66.2 | 70.2 | 67.5 | 65.7 |
| 6 Max. | 85.0 | 76.9 | 72.6 | 85.9 | 77.1 | 70.5 | 82.8 | 72.3 | 67.3 | 82.1 | 71.9 | 69.0 | 81.1 | 70.7 | 67.8 |
| 6 Min. | 70.0 | 71.5 | 70.3 | 68.8 | 71.1 | 69.2 | 71.3 | 70.8 | 67.1 | 70.8 | 69.8 | 68.8 | 74.5 | 70.6 | 67.1 |
| 7 Max. | 84.6 | 77.5 | 73.6 | 84.7 | 77.4 | 71.4 | 82.9 | 73.6 | 68.7 | 82.3 | 73.2 | 70.4 | 81.9 | 72.5 | 69.2 |
| 7 Min. | 71 4 | 73.1 | 71.6 | 69.8 | 72.4 | 70.3 | 72 6 | 72.2 | 68.6 | 71.8 | 70.9 | 70.0 | 76.2 | 72.4 | 68.5 |
| 8 Max. | 84.9 | 77.6 | 74.1 | 84.4 | 77.3 | 72.0 | 83.1 | 74.4 | 69.8 | 82.5 | 73.8 | 71.2 | 82.2 | 73.9 | 70.3 |
| 8 Min. | 73.5 | 73 5 | 72.6 | 72.4 | 73.1 | 71.1 | 74.4 | 73.4 | 69.6 | 73.8 | 72.3 | 70.9 | 77.0 | 73.7 | 69.8 |
| 9 Max. | 86.0 | 78.2 | 74.6 | 85.4 | 77.9 | 72.4 | 84.1 | 74.6 | 70.3 | 83.3 | 73.9 | 71.9 | 83.1 | 74.8 | 71.3 |
| 9 Min. | 72.4 | 73.9 | 72 7 | 70.6 | 73.3 | 71.3 | 73.7 | 73.6 | 70.1 | 72.7 | 72.1 | 71.3 | 77.4 | 74.5 | 70.9 |
| 10 Max. | 88.6 | 80.2 | 76.1 | 87.7 | 79.8 | 73.5 | 86.6 | 76.2 | 71.0 | 85.7 | 75.3 | 72.6 | 85.4 | 75.7 | 72.0 |
| 10 Min. | 73.9 | 75.0 | 74.8 | 72.3 | 74.5 | 72.2 | 74.9 | 74.6 | 70.9 | 74.1 | 73.3 | 72.2 | 78.3 | 75.4 | 71.7 |
| 11 Max. | 87.4 | 80.8 | 77.4 | 86.3 | 80.1 | 74.7 | 86.1 | 77.7 | 72.1 | 85.5 | 76.9 | 73.8 | 85.9 | 77.0 | 73.1 |
| 11 Min. | 77.5 | 77.4 | 75.8 | 76.1 | 76.6 | 74.0 | 78.2 | 76.6 | 71.9 | 77.4 | 75.1 | 73.4 | 81.2 | 76.9 | 72.7 |
| 13 Max. | 80.4 | 77.0 | 76.8 | 78.6 | 76.7 | 75.3 | 79.6 | 77.9 | 73.7 | 79.5 | 76.8 | 74.8 | 81.1 | 78.2 | 74.7 |
| 13 Min. | 76.0 | 76.9 | 75.8 | 73 9 | 76.0 | 74.3 | 77.7 | 77.0 | 73.4 | 77.0 | 75.9 | 74.5 | 80.6 | 77.9 | 74.5 |
| 14 Max. | 73.6 | 73.8 | 74.1 | 72.6 | 73.3 | 73.4 | 74.6 | 75.6 | 72.9 | 74.4 | 74.4 | 73.9 | 77.6 | 77.4 | 74.9 |
| 14 Min. | 72.4 | 73.0 | 72.6 | 71.0 | 72.5 | 71.9 | 74.4 | 74.1 | 71.9 | 73.9 | 73.6 | 72.8 | 76.5 | 76.5 | 74.6 |
| 15 Max. | 77.9 | 73.6 | 71.8 | 78.4 | 73.6 | 71.2 | 77.1 | 73.0 | 71.2 | 77.0 | 72.4 | 72.0 | 76.9 | 75.5 | 74.1 |
| 15 Min. | 69.8 | 70.7 | 70.9 | 68.7 | 70.4 | 70.4 | 71.4 | 72.1 | 70.3 | 71.2 | 71.7 | 71.1 | 74.1 | 74.6 | 73.6 |
| 16 Max. | 85.2 | 77.6 | 73.9 | 86.6 | 79.1 | 72.8 | 84.0 | 74.1 | 70.4 | 83.4 | 73.8 | 71.4 | 81.5 | 74.8 | 73.1 |
| 16 Min. | 71.0 | 72.0 | 71.7 | 70.1 | 71.6 | 70.9 | 72.5 | 72.6 | 70.1 | 72.2 | 71.8 | 71.1 | 75.2 | 74.1 | 72.6 |
| 17 Max. | 86.3 | 79.9 | 76.6 | 87.3 | 80.5 | 74.9 | 85.4 | 76.6 | 71.5 | 84.3 | 76.5 | 73.1 | 84.1 | 76.8 | 73.0 |
| 17 Min. | 74 6 | 75 6 | 74.4 | 75.1 | 76.1 | 73.7 | 76.9 | 75.4 | 71.3 | 76.1 | 74.6 | 72.9 | 78.9 | 75.6 | 72.8 |
| 18 Max. | 76.6 | 75.2 | 75.5 | 76.1 | 74.8 | 74.8 | 76.5 | 76.6 | 72.6 | 75.6 | 75.5 | 74.0 | 78.6 | 76.9 | 73.7 |
| 18 Min. | 72 5 | 73.8 | 73.5 | 71.3 | 73.6 | 72.8 | 74.5 | 74.6 | 72.0 | 73.4 | 73.5 | 73.0 | 77.3 | 76.1 | 73 6 |
| 20 Max. | 83.6 | 75.9 | 72.4 | 83.6 | 76.1 | 71.2 | 81.8 | 72.6 | 70.0 | 80.5 | 72.1 | 70.7 | 79.6 | 73.8 | 72.6 |
| 20 Min. | 67.7 | 70 0 | 70 0 | 66.1 | 69 8 | 69.7 | 69.2 | 70.9 | 69.5 | 68.5 | 69.9 | 70.1 | 73.0 | 73.1 | 71.9 |
| 21 Max. | 83.9 | 77.8 | 74.3 | 84.1 | 77.5 | 72.6 | 83.2 | 74.1 | 70.4 | 82.1 | 72.7 | 71.4 | 81.7 | 74.1 | 71.9 |
| 21 Min. | 71 2 | 72 9 | 72 3 | 69.9 | 72 6 | 71.5 | 72.3 | 72.8 | 70.1 | 71.3 | 73.0 | 71.1 | 75.9 | 73.9 | 71.8 |
| 22 Max. | 85.6 | 79.6 | 76.1 | 85.6 | 79.2 | 74.0 | 85.4 | 76.1 | 71.4 | 84.1 | 73.9 | 72.7 | 84.1 | 75.4 | 72.6 |
| 22 Min. | 73 8 | 75 4 | 74.1 | 73 1 | 74 9 | 72.9 | 75.5 | 74.5 | 71.2 | 74.5 | 73.5 | 72.2 | 78.5 | 75.2 | 72.3 |
| 23 Max. | 79.4 | 77.6 | 76.9 | 78.3 | 77.1 | 75.2 | 80.3 | 77.4 | 72.7 | 79.8 | 75.1 | 74.0 | 81.1 | 76.9 | 73.7 |
| 23 Min. | 76.9 | 76.9 | 75 9 | 76 6 | 76 4 | 74.4 | 78 4 | 76.6 | 72.5 | 77.8 | 74.4 | 73.8 | 80.3 | 76.7 | 73.1 |
| 24 Max. | 80.1 | 77.4 | 75.4 | 77.8 | 77.1 | 74.0 | 77.3 | 76.0 | 72.7 | 76.7 | 74.7 | 74.0 | 80.6 | 76.9 | 74.1 |
| 24 Min. | 73.9 | 74.3 | 74.2 | 72.1 | 74.5 | 73.3 | 75.9 | 73.9 | 72.4 | 75.4 | 72.3 | 73.5 | 77.9 | 76.2 | 73.9 |
| 25 Max. | 86.4 | 80.3 | 76.8 | 84.9 | 79.9 | 74.6 | 85.9 | 76.9 | 72.5 | 84.6 | 76.5 | 73.4 | 84.6 | 76.5 | 74.0 |
| 25 Min. | 72 3 | 74.5 | 74.0 | 70.9 | 74.0 | 72.9 | 74.6 | 74 8 | 72.1 | 74.0 | 73.4 | 73.4 | 77.4 | 76.3 | 74 0 |
| 27 Max. | 78.8 | 77.6 | 77.3 | 77.8 | 77.0 | 75.8 | 78.8 | 78.0 | 73.9 | 78.1 | 76.4 | 75.3 | 80.6 | 78.2 | 75.8 |
| 27 Min. | 75.5 | 77.0 | 76.3 | 74 0 | 76.2 | 74 8 | 77.6 | 76.9 | 73.7 | 76.6 | 74.9 | 74.6 | 80.2 | 77.8 | 74.8 |
| 28 Max. | 78.3 | 74.9 | 73.7 | 77.8 | 74.7 | 73.0 | 78.7 | 75.0 | 73.2 | 78.3 | 72.8 | 74,1 | 78.6 | 77.3 | 75.2 |
| 28 Min. | 68.9 | 72.1 | 72 6 | 66.6 | 71 3 | 71.9 | 72.0 | 73.9 | 72.2 | 71.4 | 71.8 | 72.9 | 75.5 | 76.1 | 74.8 |
| 29 Max. | 79.6 | 74.3 | 71.9 | 78.9 | 74.4 | 71.8 | 79.1 | 73.4 | 71.8 | 78.2 | 71.4 | 72.5 | 78.1 | 76.0 | 74.5 |
| 29 Min. | 69.4 | 69.6 | 70 4 | 68.5 | 68 9 | 70.1 | 70.0 | 71.7 | 70.8 | 69.8 | 70.3 | 71.4 | 72.8 | 74.6 | 73.9 |
| 30 Max. | 81.0 | 75.1 | 72.4 | 80.8 | 75.1 | 71.6 | 80.0 | 73.0 | 71.1 | 78.9 | 71.1 | 71.8 | 78.3 | 74.9 | 73.6 |
| 30 Min. | 66 0 | 70.3 | 70 6 | 63 4 | 69 8 | 70.3 | 68 8 | 71.5 | 70.1 | 67.8 | 69.6 | 70.9 | 72.8 | 73.9 | 73.0 |
| 31 Max. | 80.4 | 75.8 | 73.3 | 78.4 | 75.4 | 72.2 | 79.9 | 73.4 | 70.8 | 78.9 | 72.3 | 71.7 | 78.8 | 74.6 | 73.0 |
| 31 Min. | 69 7 | 71 7 | 71 8 | 67.2 | 71 3 | 71.3 | 71.4 | 72 3 | 70.4 | 70.5 | 70.9 | 71.1 | 74.2 | 73.9 | 72.7 |
| Ave. Max | 80.74 | 75.89 | 73.50 | 80.58 | 75.84 | 72.11 | 80.03 | 73.90 | 70.36 | 79.42 | 73.00 | 71.56 | 79.67 | 74.33 | 71.92 |
| Ave. Min | 70.88 | 72.28 | 71.86 | 69.33 | 71.86 | 70.90 | 72.47 | 72.58 | 69.94 | 71.90 | 71.45 | 71.02 | 75.39 | 73.81 | 71.56 |
| Ave. Range | 9.86 | 3.61 | 1.64 | 11.25 | 3.98 | 1.21 | 7.56 | 1.32 | 0.42 | 7.52 | 1.55 | 0.54 | 4.28 | 0.52 | 0.36 |

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TABLE 59.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, AUGUST, 1914.

| Date— | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 Max.... | 82.1 | 77.1 | 74.5 | 80.4 | 76.5 | 72.6 | 81.5 | 74.2 | 70.9 | 80.7 | 72.6 | 71.9 | 80.4 | 74.6 | 72.6 |
| 1 Min.... | 70.8 | 73.4 | 72.9 | 69.8 | 72.9 | 71.8 | 72.6 | 73.1 | 70.8 | 71.7 | 70.4 | 71.6 | 75.6 | 74.1 | 72.5 |
| 3 Max.... | 82.1 | 77.4 | 74.6 | 81.0 | 76.6 | 73.2 | 82.0 | 74.8 | 71.8 | 81.0 | 73.4 | 72.9 | 80.6 | 75.4 | 73.3 |
| 3 Min.... | 71.1 | 73.6 | 73.2 | 69.3 | 72 8 | 72.1 | 73.3 | 73.8 | 71.5 | 72.3 | 72.2 | 72.4 | 76.3 | 74.9 | 73.2 |
| 4 Max.... | 83.3 | 76.9 | 74.1 | 81.8 | 75.8 | 73.0 | 81.6 | 74.6 | 72.0 | 80.6 | 73.0 | 73.1 | 79.2 | 75.7 | 73.5 |
| 4 Min.... | 68.7 | 72.3 | 72.5 | 67.4 | 71.4 | 71.7 | 70.8 | 73.1 | 71.4 | 69.8 | 70.7 | 72.1 | 74.6 | 74.9 | 73.4 |
| 5 Max.... | 83.8 | 77.0 | 74.1 | 82.2 | 75.8 | 73.1 | 81.8 | 74.6 | 71.9 | 80.6 | 72.5 | 72.9 | 79.8 | 75.5 | 73.6 |
| 5 Min.... | 70.4 | 72 7 | 72.8 | 68.9 | 71.8 | 71.9 | 71.7 | 73.2 | 71.2 | 70.6 | 70.8 | 72.0 | 74.5 | 74.9 | 73.3 |
| 6 Max.... | 76.7 | 77.0 | 74.7 | 81.0 | 75.9 | 73.5 | 81.2 | 74.9 | 71.9 | 80.4 | 72.9 | 72.9 | 79.5 | 75.6 | 73.5 |
| 6 Min.... | 72.5 | 73.7 | 73.7 | 71.6 | 72.9 | 72.6 | 73.6 | 74.0 | 71.5 | 72.6 | 72.2 | 72.5 | 75.1 | 75.0 | 73.5 |
| 7 Max.... | 86.0 | 79.3 | 76.1 | 84.6 | 78.0 | 73.8 | 84.8 | 75.9 | 72.1 | 83.6 | 74.1 | 73.4 | 82.6 | 75.6 | 73.6 |
| 7 Min.... | 73.5 | 74.8 | 74.1 | 71.8 | 73.9 | 72.9 | 74.6 | 74.6 | 71.9 | 73.6 | 72.8 | 73.0 | 77.3 | 75.4 | 73.6 |
| 8 Max.... | 87.9 | 80.0 | 76.9 | 85.8 | 78.6 | 74.9 | 85.8 | 76.8 | 72.9 | 84.6 | 74.9 | 74.3 | 83.1 | 76.6 | 74.1 |
| 8 Min.... | 74.0 | 75.7 | 75.0 | 73.0 | 74.6 | 74.0 | 75.3 | 75.5 | 72.9 | 74.1 | 72.9 | 73.9 | 78.0 | 76.3 | 73.9 |
| 10 Max.... | 80.1 | 76.9 | 76.8 | 78.3 | 76.1 | 75.4 | 79.1 | 77.3 | 74.1 | 78.7 | 75.8 | 75.3 | 79.1 | 77.6 | 75.3 |
| 10 Min.... | 75.3 | 76.4 | 75.8 | 74.4 | 75.5 | 74.6 | 76.4 | 76.5 | 73.9 | 75.7 | 75.0 | 74.8 | 78.0 | 77.3 | 75.0 |
| 11 Max.... | 78.6 | 73.7 | 73.7 | 76.9 | 73.8 | 73.1 | 76.2 | 74.9 | 73.5 | 75.9 | 73.8 | 74.3 | 77.0 | 76.9 | 75.4 |
| 11 Min.... | 73.1 | 71.5 | 72.4 | 72.6 | 70.7 | 71.8 | 71.5 | 73.9 | 72.3 | 70.8 | 72.0 | 72.9 | 74.6 | 75.3 | 74.9 |
| 12 Max.... | 79.1 | 73.5 | 71.4 | 80.1 | 73.8 | 71.3 | 78.2 | 72.7 | 71.9 | 77.3 | 71.2 | 72.6 | 76.1 | 75.4 | 74.6 |
| 12 Min.... | 65.5 | 69.0 | 69.8 | 62.9 | 68.6 | 70.1 | 68.4 | 71 3 | 70.8 | 67.7 | 70.1 | 71.2 | 71.7 | 74.1 | 74.0 |
| 13 Max.... | 72.9 | 71.7 | 71.5 | 73.0 | 71.4 | 71.4 | 72.8 | 72.8 | 70.9 | 72.3 | 71.7 | 71.7 | 73.9 | 74.1 | 73.5 |
| 13 Min.... | 68.6 | 70.7 | 70.9 | 67.3 | 70.4 | 70.8 | 70.6 | 71.9 | 70.5 | 69.9 | 71.1 | 71.1 | 72.9 | 73.6 | 73.1 |
| 14 Max.... | 70.9 | 70.2 | 69.8 | 70.6 | 70.4 | 69.5 | 71.6 | 70.5 | 70.0 | 71.7 | 69.9 | 70.7 | 71.9 | 72.8 | 72.6 |
| 14 Min.... | 65.1 | 67.9 | 68.7 | 63.0 | 67.4 | 68.8 | 66.8 | 69.6 | 69.2 | 66.5 | 68.9 | 69.7 | 69.9 | 71.9 | 72.1 |
| 15 Max.... | 78.7 | 71.0 | 69.0 | 78.6 | 72.1 | 68.8 | 75.8 | 69.3 | 68.9 | 67.6 | 69.2 | 69.5 | 72.2 | 71.4 | 71.7 |
| 15 Min.... | 62.5 | 66.1 | 67.0 | 59.8 | 66.1 | 67.6 | 64.6 | 68.0 | 68.1 | 64.4 | 67.4 | 68.5 | 67.6 | 70.4 | 71.0 |
| 17 Max.... | 75.6 | 72.0 | 70.5 | 76.4 | 72.6 | 69.9 | 74.9 | 70.4 | 68.4 | 75.4 | 70.6 | 69.4 | 73.8 | 70.4 | 70.0 |
| 17 Min.... | 67.4 | 69.3 | 69.3 | 66.6 | 69.1 | 69.1 | 68.9 | 69.7 | 68.2 | 68.6 | 69.3 | 69.2 | 70.2 | 70.1 | 69.8 |
| 18 Max.... | 80.6 | 74.8 | 72.2 | 82.1 | 75.4 | 71.1 | 79.0 | 71.8 | 69.0 | 79.1 | 72.1 | 70.1 | 76.7 | 71.0 | 70.0 |
| 18 Min.... | 70.7 | 71.0 | 70.7 | 70.2 | 70.9 | 70.3 | 71.7 | 70.9 | 68.8 | 71.6 | 70.9 | 70.0 | 72.7 | 70.9 | 69.9 |
| 19 Max.... | 78.8 | 75.5 | 73.6 | 78.5 | 75.7 | 72.3 | 78.4 | 73.5 | 70.0 | 78.8 | 73.6 | 71.4 | 77.4 | 72.4 | 70.7 |
| 19 Min.... | 71.7 | 72.7 | 72.2 | 70.8 | 72.4 | 71.5 | 73.1 | 72.5 | 69.9 | 72.9 | 72.3 | 71.0 | 74.5 | 72.1 | 70.7 |
| 20 Max.... | 78.5 | 75.4 | 73.7 | 78.0 | 75.5 | 72.5 | 78.3 | 73.7 | 70.6 | 78.4 | 73.8 | 72.1 | 77.2 | 73.1 | 71.5 |
| 20 Min.... | 72.1 | 72.9 | 72.6 | 71.3 | 72.6 | 71.9 | 73.4 | 72.9 | 70.6 | 73.2 | 72.8 | 71.7 | 74.7 | 73.0 | 71.2 |
| 21 Max.... | 80.6 | 76.0 | 73.7 | 81.6 | 76.6 | 72.6 | 80.5 | 73.9 | 71.1 | 80.2 | 74.0 | 72.3 | 77.9 | 73.6 | 72.0 |
| 21 Min.... | 70.7 | 72.0 | 72.1 | 69.8 | 71.8 | 71.7 | 72.4 | 72.9 | 70.7 | 72.3 | 72.4 | 71.9 | 74.0 | 73.3 | 71.7 |
| 22 Max.... | 80.2 | 75.9 | 73.7 | 81.8 | 76.4 | 72.6 | 80.2 | 73.9 | 71.4 | 79.6 | 73.6 | 72.6 | 77.7 | 74.1 | 72.3 |
| 22 Min.... | 68.6 | 71.9 | 71.8 | 67.5 | 71.5 | 71.4 | 71.3 | 72.8 | 70.9 | 70.9 | 72.2 | 71.9 | 73.6 | 73.5 | 72.2 |
| 24 Max.... | 72.8 | 73.2 | 73.8 | 72.4 | 72.9 | 73:1 | 73.4 | 74.2 | 71.6 | 72.6 | 73.6 | 72.8 | 74.9 | 74.5 | 72.8 |
| 24 Min.... | 70.9 | 71.7 | 72.1 | 69.8 | 71.3 | 71.6 | 71.4 | 72.7 | 71.1 | 70.9 | 71.9 | 71.9 | 73.3 | 73.9 | 72.7 |
| 25 Max.... | 75.4 | 70.9 | 69.4 | 75.9 | 71.0 | 69.5 | 74.6 | 70.3 | 70.6 | 73.4 | 69.2 | 70.9 | 72.6 | 73.1 | 72.6 |
| 25 Min.... | 61.8 | 66 3 | 67.9 | 59.2 | 65.6 | 68.2 | 63.8 | 69.0 | 69.0 | 63.1 | 67.6 | 69.4 | 67.2 | 71.4 | 72.0 |
| 26 Max.... | 75.2 | 70.7 | 69.2 | 74.7 | 70.9 | 69.3 | 74.1 | 69.9 | 69.1 | 73.2 | 68.7 | 69.6 | 72.6 | 71.6 | 71.5 |
| 26 Min.... | 63.6 | 66.8 | 67.9 | 61.5 | 66.4 | 68.0 | 65.4 | 68.4 | 68.1 | 64.4 | 67.2 | 68.4 | 67.8 | 70.5 | 70.8 |
| 27 Max.... | 77.3 | 72.4 | 70.4 | 77.0 | 72.6 | 69.5 | 76.6 | 70.1 | 68.3 | 75.4 | 69.5 | 68.9 | 74.9 | 70.8 | 70.5 |
| 27 Min.... | 66.8 | 68.6 | 68.7 | 64.0 | 68.3 | 68.6 | 67.8 | 68.9 | 67.9 | 66.9 | 68.1 | 68.6 | 69.8 | 70.3 | 70.2 |
| 28 Max.... | 70.3 | 70.0 | 70.1 | 69.6 | 69.6 | 69.9 | 70.6 | 70.5 | 68.6 | 70.0 | 69.4 | 69.5 | 71.6 | 71.0 | 70.2 |
| 28 Min.... | 66.6 | 68.6 | 69.1 | 64.9 | 68.0 | 69.0 | 67.5 | 69.3 | 68.3 | 66.7 | 68.4 | 68.9 | 69.8 | 70.5 | 70.1 |
| 29 Max.... | 69.6 | 68.1 | 67.7 | 69.7 | 68.0 | 68.0 | 69.6 | 68.3 | 68.1 | 69.5 | 67.3 | 68.4 | 69.0 | 70.2 | 70.1 |
| 29 Min.... | 62.4 | 65.2 | 66.6 | 60.4 | 64.7 | 66.8 | 64.1 | 67.1 | 66.9 | 63.8 | 66.3 | 67.2 | 66.4 | 69.3 | 69.5 |
| 31 Max.... | 72.9 | 69.3 | 67.5 | 73.2 | 69.4 | 67.0 | 71.9 | 67.1 | 65.8 | 72.0 | 67.1 | 66.4 | 69.4 | 67.5 | 68.3 |
| 31 Min.... | 64.6 | 65.4 | 66.0 | 63.6 | 65.2 | 66.0 | 65.1 | 66 1 | 65.6 | 65.0 | 65.6 | 66.0 | 66.4 | 67 2 | 67.8 |
| Ave. Max.. | 78.00 | 74.07 | 72.41 | 77.89 | 73.90 | 71.57 | 77.48 | 72.73 | 70.58 | 76.64 | 71.83 | 71.53 | 76.20 | 73.48 | 72.30 |
| Ave. Min.. | 68.81 | 70.78 | 70.99 | 67.36 | 70.26 | 70.57 | 70.24 | 71.60 | 70.08 | 69.62 | 70.44 | 70.84 | 72.56 | 72.85 | 72.00 |
| Ave. Range | 9.19 | 3.29 | 1.42 | 10.53 | 3.64 | 1.00 | 7.24 | 1.13 | 0.51 | 7.02 | 1.39 | 0.69 | 3.64 | 0.63 | 0.30 |

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TABLE 60.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, SEPTEMBER, 1914.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" | 6" | 12" | 18" |
| 1 | Max.... | 74.2 | 71.2 | 69.6 | 73.1 | 71.7 | 69.2 | 73.8 | 69.2 | 66.9 | 73.9 | 69.3 | 67.7 | 71.6 | 68.2 | 67.8 |
| | Min.... | 68.6 | 68.6 | 68.4 | 67.4 | 68.4 | 68.1 | 68.9 | 68.5 | 66.8 | 68.9 | 68.1 | 67.5 | 69.4 | 67.9 | 67.6 |
| 2 | Max.... | 69.7 | 69.5 | 69.5 | 69.2 | 69.4 | 69.3 | 70.4 | 69.6 | 67.4 | 70.4 | 69.3 | 68.5 | 70.4 | 68.9 | 68.4 |
| | Min.... | 68.6 | 68.9 | 69.0 | 67.1 | 68.5 | 68.7 | 69.4 | 69.1 | 67.3 | 69.2 | 68.8 | 68.4 | 69.6 | 68.9 | 68.0 |
| 3 | Max.... | 68.8 | 67.1 | 66.8 | 68.1 | 67.9 | 67.2 | 69.4 | 67.6 | 67.2 | 69.1 | 66.9 | 68.1 | 68.3 | 68.9 | 68.6 |
| | Min.... | 61.4 | 64.8 | 65.8 | 58.8 | 64.6 | 66.3 | 63.2 | 66.5 | 66.4 | 63.0 | 65.9 | 66.9 | 65.7 | 68.2 | 68.5 |
| 4 | Max.... | 69.1 | 66.1 | 65.6 | 69.9 | 66.4 | 66.2 | 68.5 | 66.3 | 66.3 | 68.0 | 65.7 | 66.9 | 66.8 | 68.0 | 68.3 |
| | Min.... | 59.5 | 63.0 | 64.6 | 56.5 | 62.7 | 65.2 | 61.9 | 65.4 | 65.4 | 61.6 | 64.6 | 65.8 | 64.1 | 66.9 | 67.8 |
| 5 | Max.... | 69.0 | 68.1 | 65.0 | 70.1 | 66.4 | 65.3 | 68.2 | 65.3 | 65.3 | 67.9 | 64.6 | 65.8 | 68.2 | 66.9 | 67.5 |
| | Min.... | 58.8 | 62.9 | 63.6 | 55.7 | 62.5 | 64.2 | 60.7 | 64.1 | 64.5 | 60.3 | 63.4 | 64.8 | 63.1 | 66.0 | 66.9 |
| 7 | Max .... | 63.2 | 63.6 | 65.1 | 63.3 | 63.6 | 65.4 | 64.6 | 65.5 | 64.9 | 64.8 | 64.9 | 65.6 | 64.7 | 66.1 | 66.3 |
| | Min.... | 60.3 | 62.8 | 63.9 | 58.9 | 62.5 | 64.3 | 62.0 | 64.3 | 64.2 | 62.0 | 63.9 | 64.8 | 63.7 | 65.7 | 66.2 |
| 8 | Max.... | 65.6 | 63.4 | 62.8 | 66.1 | 63.7 | 63.5 | 65.8 | 63.5 | 64.0 | 65.3 | 62.9 | 64.4 | 63.9 | 65.3 | 66.1 |
| | Min.... | 55.2 | 59.7 | 61.5 | 53.2 | 59.3 | 62.4 | 58.0 | 62.3 | 63.1 | 58.1 | 61.6 | 63.4 | 60.9 | 64.4 | 65.5 |
| 9 | Max.... | 67.0 | 63.9 | 62.5 | 66.9 | 64.1 | 62.6 | 66.6 | 62.5 | 63.1 | 66.1 | 62.0 | 63.6 | 64.0 | 64.2 | 65.2 |
| | Min.... | 54.7 | 59.3 | 60.8 | 52.9 | 58.7 | 61.5 | 57.1 | 61.6 | 62.1 | 56.8 | 60.8 | 62.5 | 59.4 | 63.2 | 64 6 |
| 10 | Max.... | 62.3 | 61.6 | 62.4 | 62.4 | 61.6 | 62.8 | 62.3 | 62.7 | 62.6 | 62.0 | 61.9 | 63.0 | 61.4 | 63.6 | 64.5 |
| | Min.... | 55 9 | 59.4 | 60.9 | 51.7 | 58.8 | 61.7 | 57.8 | 61.4 | 61.8 | 57.4 | 60.5 | 62.1 | 59.4 | 62.7 | 64.1 |
| 11 | Max.... | 59.7 | 59.9 | 61.3 | 59.4 | 59.7 | 61.8 | 59.8 | 61.5 | 61.7 | 59.9 | 60.8 | 62.0 | 60.0 | 62.4 | 63.7 |
| | Min.... | 57.4 | 59.3 | 60.5 | 56.3 | 58.9 | 61.0 | 58.1 | 60.5 | 61.1 | 58.1 | 60.0 | 61.5 | 59.3 | 62.0 | 63.2 |
| 12 | Max.... | 61.9 | 59.9 | 59.4 | 62.0 | 60.0 | 59.9 | 61.1 | 59.5 | 60.9 | 61.3 | 58.8 | 61.1 | 59.5 | 61.5 | 63.0 |
| | Min.... | 52.0 | 56.6 | 58.1 | 50.0 | 56.0 | 59.0 | 53.8 | 58.4 | 59.8 | 53.8 | 57.8 | 60.0 | 56.2 | 60.5 | 62.4 |
| 14 | Max.... | 68.0 | 63.4 | 61.8 | 69.4 | 64.1 | 61.7 | 66.4 | 61.1 | 60.0 | 66.5 | 61.2 | 60.9 | 63.4 | 60.6 | 61.7 |
| | Min.... | 57.4 | 50.7 | 60.2 | 56.9 | 59.6 | 60.7 | 58.4 | 60.0 | 59.8 | 58.5 | 59.8 | 60.7 | 59.8 | 60.6 | 61.5 |
| 15 | Max.... | 68.9 | 65.6 | 63.9 | 69.7 | 66.0 | 63.5 | 67.7 | 63.1 | 61.3 | 67.9 | 63.4 | 62.3 | 65.6 | 61.8 | 61.8 |
| | Min.... | 62.6 | 62.9 | 62.7 | 62.3 | 63.0 | 62.7 | 62.6 | 62.3 | 60.8 | 62.7 | 62.1 | 62.0 | 62.9 | 61.5 | 61 6 |
| 16 | Max.... | 73.6 | 68.6 | 66.0 | 73.0 | 69.2 | 65.0 | 72.4 | 65.1 | 62.3 | 71.9 | 65.4 | 63.4 | 69.3 | 63.1 | 62.6 |
| | Min.... | 62 9 | 64.1 | 63.8 | 62.1 | 63.9 | 63.6 | 63.6 | 63.6 | 62.0 | 63.6 | 63.4 | 63.1 | 64.2 | 62.7 | 62.2 |
| 17 | Max .... | 73.4 | 68.5 | 66.1 | 74.6 | 68.9 | 65.3 | 72.2 | 65.5 | 63.4 | 71.3 | 65.4 | 64.6 | 69.5 | 64.3 | 63.5 |
| | Min.... | 61.1 | 63.8 | 64.2 | 57.3 | 63.3 | 64.1 | 62.4 | 64.2 | 63.1 | 62.0 | 63.6 | 64.1 | 63.7 | 64.1 | 63.2 |
| 18 | Max .. | 73.9 | 68.7 | 66.3 | 73.1 | 68.9 | 65.5 | 72.4 | 65.9 | 64.0 | 71.5 | 65.6 | 65.0 | 69.7 | 65.2 | 64.2 |
| | Min.... | 61.5 | 64.1 | 64.6 | 59.5 | 63.7 | 64.4 | 62.8 | 64.7 | 63.6 | 62.2 | 63.9 | 64.3 | 64.0 | 64.8 | 64.1 |
| 19 | Max.... | 74.9 | 69.2 | 66.7 | 75.1 | 69.4 | 65.9 | 73.4 | 66.3 | 64.4 | 72.3 | 66.0 | 65.2 | 70.5 | 65.8 | 64.9 |
| | Min.... | 62 5 | 64.4 | 65 1 | 60 9 | 64.0 | 64.9 | 63.6 | 65.3 | 64.1 | 62.9 | 64.4 | 64.6 | 64.9 | 65.4 | 64.6 |
| 21 | Max.... | 78.0 | 72.6 | 69.7 | 78.8 | 72.4 | 68.2 | 76.9 | 69.3 | 65.7 | 76.2 | 69.0 | 66.6 | 74.9 | 67.6 | 66.2 |
| | Min.... | 67.5 | 68.5 | 67.9 | 66.4 | 68.2 | 67.1 | 67.9 | 67.7 | 65.4 | 67.2 | 67.2 | 66.4 | 69.9 | 67.4 | 65.9 |
| 22 | Max.... | 74.1 | 71.7 | 70.4 | 73.8 | 71.5 | 69.1 | 74.0 | 70.2 | 66.9 | 73.6 | 69.9 | 68.0 | 73.6 | 69.1 | 67.1 |
| | Min.... | 70.2 | 70.2 | 69.5 | 69.7 | 69.9 | 68.7 | 70.6 | 69.5 | 66.7 | 70.1 | 69.1 | 67.9 | 71.9 | 68.8 | 66.7 |
| 23 | Max.... | 65.0 | 67.5 | 68.6 | 64.6 | 67.0 | 68.3 | 65.9 | 69.1 | 67.2 | 65.5 | 68.4 | 68.2 | 69.8 | 69.5 | 68.0 |
| | Min.... | 63.7 | 65.6 | 66 4 | 62.5 | 65.3 | 66.3 | 65.1 | 67.0 | 66.6 | 65.1 | 66.5 | 67.1 | 67.4 | 68.8 | 67 8 |
| 24 | Max.... | 62.2 | 61.6 | 63.4 | 60.4 | 61.4 | 64.1 | 62.4 | 64.6 | 65.5 | 62.3 | 63.7 | 65.9 | 63.1 | 67.9 | 67.9 |
| | Min.... | 55.3 | 59.9 | 62.0 | 52.8 | 59.2 | 62.4 | 57.7 | 62.7 | 64.0 | 57.7 | 62.0 | 64.1 | 61.6 | 66.3 | 67 1 |
| 25 | Max.... | 63.4 | 61.3 | 61.0 | 62.3 | 61.6 | 61.8 | 63.2 | 61.8 | 63.0 | 62.9 | 60.9 | 63.2 | 62.4 | 65.3 | 66.5 |
| | Min.... | 53.8 | 58.1 | 59.8 | 51.1 | 57.7 | 60.8 | 55 8 | 60.7 | 61.9 | 56.0 | 59.7 | 61.5 | 59.3 | 64.1 | 65.7 |
| 26 | Max.... | 64.0 | 61.5 | 60.5 | 64.8 | 61.8 | 61.3 | 63.3 | 60.9 | 61.6 | 63.0 | 60.0 | 62.0 | 62.4 | 63.6 | 65.0 |
| | Min.... | 53.0 | 57.4 | 59.0 | 51.2 | 56.8 | 60.0 | 55.0 | 59.6 | 60.8 | 55.0 | 58.8 | 60.3 | 58.2 | 62.5 | 64.1 |
| 28 | Max.... | 65.6 | 62.0 | 60.9 | 66.0 | 62.2 | 61.5 | 64.1 | 60.9 | 60.8 | 63.6 | 60.2 | 61.3 | 62.4 | 62.1 | 62.9 |
| | Min.... | 55.3 | 58.5 | 59.7 | 52.7 | 58.1 | 60.4 | 56.6 | 59 7 | 60.0 | 56.3 | 58.9 | 59.9 | 58.8 | 61.5 | 62.4 |
| 29 | Max.... | 67.5 | 63.2 | 61.7 | 68.2 | 63.4 | 61.5 | 65.6 | 61.0 | 60.5 | 65.4 | 61.0 | 61.3 | 63.8 | 61.8 | 62.5 |
| | Min.... | 56.8 | 59.5 | 60.1 | 54.4 | 59.1 | 60.8 | 57.6 | 60.0 | 60.3 | 57.4 | 59.5 | 60.7 | 59.9 | 61.5 | 62.2 |
| 30 | Max.... | 66.9 | 63.4 | 62.3 | 67.3 | 63.6 | 62.3 | 65.1 | 62.0 | 60.9 | 65.2 | 61.5 | 61.8 | 64.3 | 62.1 | 62.3 |
| | Min.... | 57.4 | 60.3 | 61.0 | 56.2 | 59.9 | 61.5 | 58.4 | 60.9 | 60.6 | 58.1 | 60.4 | 60.6 | 60.6 | 61.9 | 62.1 |
| Ave. | Max | 68.07 | 65.43 | 64.59 | 68.14 | 65.61 | 64.56 | 67.52 | 64.61 | 63.76 | 67.22 | 64.19 | 64.48 | 66.21 | 65.14 | 65.28 |
| | Min | 59.75 | 62.40 | 63.20 | 57.86 | 62.02 | 63.50 | 61.12 | 63.46 | 63.17 | 60.92 | 62.87 | 63.66 | 62.99 | 64.55 | 64.84 |
| | Range | 8.32 | 3.03 | 1.39 | 10.28 | 3.59 | 1.06 | 6.40 | 1.15 | 0.59 | 6.30 | 1.32 | 0.82 | 3.22 | 0.59 | 0.41 |

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TABLE 61.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, OCTOBER, 1914.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 1 | Max.... | 66.5 | 62.9 | 61.5 | 66.9 | 62.6 | 62.0 | 64.3 | 61.4 | 61.2 | 64.4 | 60.9 | 61.8 | 63.3 | 62.3 | 62.4 |
| | Min.... | 55.2 | 58.8 | 60.0 | 53.6 | 58.3 | 60.6 | 56.3 | 59.9 | 60.4 | 55.9 | 59.0 | 60.9 | 58.9 | 61.5 | 62.2 |
| 2 | Max.... | 65.9 | 62.4 | 61.1 | 62.1 | 62.1 | 61.5 | 63.7 | 60.8 | 60.9 | 63.7 | 60.0 | 61.5 | 62.7 | 62.0 | 62.4 |
| | Min.... | 54.7 | 58.3 | 59.6 | 53.3 | 57.7 | 60.3 | 55.7 | 59.4 | 59.9 | 55.4 | 58.5 | 60.4 | 58.4 | 61.3 | 62.0 |
| 3 | Max.... | 64.2 | 61.6 | 60.8 | 64.3 | 61.4 | 61.3 | 62.6 | 60.5 | 60.3 | 62.7 | 59.7 | 60.9 | 61.9 | 61.8 | 62.1 |
| | Min.... | 55.5 | 58.3 | 59.5 | 54 5 | 57.9 | 60.0 | 56.1 | 59.2 | 59.6 | 55.9 | 58.4 | 59.9 | 58.3 | 60.9 | 61.9 |
| 5 | Max.... | 68.4 | 64.7 | 63.0 | 68.6 | 64.5 | 62.2 | 66.7 | 62.1 | 60.0 | 66.9 | 62.1 | 61.1 | 65.6 | 61.4 | 61.5 |
| | Min.... | 61.6 | 61.8 | 61.6 | 61.1 | 61.6 | 61.5 | 61.3 | 61.1 | 59.8 | 61.3 | 60.7 | 60.8 | 62.3 | 61.2 | 61.4 |
| 6 | Max.... | 70.2 | 66.1 | 64.2 | 70.4 | 65.7 | 63.4 | 68.6 | 63.4 | 61.4 | 68.6 | 63.5 | 62.3 | 67.1 | 62.5 | 62.0 |
| | Min.... | 63.0 | 63.4 | 63.1 | 62.4 | 63.1 | 62.8 | 62.9 | 62.6 | 61.2 | 62.9 | 62.5 | 62.0 | 64.1 | 62.3 | 61.8 |
| 7 | Max.... | 70.8 | 66.4 | 64.5 | 70.8 | 65.9 | 63.8 | 68.9 | 63.9 | 62.1 | 69.1 | 63.9 | 63.3 | 67.4 | 63.4 | 62.6 |
| | Min.... | 62.3 | 63.4 | 63.5 | 61.8 | 62.9 | 63.2 | 62.6 | 63.3 | 61.9 | 62.4 | 62.8 | 62.7 | 64.1 | 63.1 | 62.5 |
| 8 | Max.... | 67.6 | 65.6 | 65.1 | 66.7 | 65.4 | 64.4 | 67.0 | 64.8 | 62.7 | 67.1 | 64.7 | 63.7 | 66.7 | 64.1 | 63.2 |
| | Min.... | 64.0 | 64.7 | 64.6 | 63.1 | 64.2 | 64.1 | 64.4 | 64.3 | 62.6 | 64.2 | 64.1 | 63.7 | 65.6 | 64.1 | 63.1 |
| 9 | Max.... | 70.3 | 66.8 | 65.1 | 70.6 | 66.8 | 64.3 | 69.2 | 65.0 | 62.9 | 69.4 | 65.0 | 63.9 | 68.1 | 64.4 | 63.7 |
| | Min.... | 63.1 | 63.9 | 63.9 | 61.1 | 63.6 | 63.6 | 63.6 | 64.0 | 62.7 | 63.7 | 63.7 | 63.4 | 65.0 | 64.3 | 63.6 |
| 10 | Max.... | 65.6 | 65.2 | 65.3 | 65.3 | 65.0 | 64.7 | 65.7 | 65.3 | 63.3 | 65.7 | 65.3 | 64.4 | 66.6 | 65.0 | 64.1 |
| | Min.... | 64.7 | 64.7 | 64.7 | 63.8 | 64.4 | 64.3 | 65.1 | 64.8 | 63.2 | 65.1 | 64.7 | 64.1 | 66.0 | 64.8 | 64.0 |
| 12 | Max.... | 57.1 | 58.8 | 60.2 | 55.7 | 58.4 | 60.9 | 58.0 | 61.1 | 62.0 | 58.1 | 60.5 | 62.4 | 59.8 | 63.6 | 64.2 |
| | Min.... | 53.8 | 57.4 | 59.2 | 51.4 | 56.8 | 59.8 | 55.8 | 59.9 | 60.7 | 55.5 | 59.4 | 60.9 | 58.5 | 62.3 | 63.6 |
| 13 | Max.... | 54.0 | 56.9 | 58.4 | 52.1 | 56.6 | 59.2 | 55.3 | 58.9 | 60.0 | 55.6 | 58.5 | 60.4 | 58.1 | 61.8 | 63.1 |
| | Min.... | 52.9 | 55.7 | 57.4 | 51.0 | 55.4 | 58.1 | 54.0 | 57.8 | 59.1 | 54.1 | 57.4 | 59.5 | 56.9 | 60.9 | 62.6 |
| 14 | Max.... | 52.6 | 53.6 | 55.4 | 51.1 | 53.5 | 56.8 | 52.7 | 56.0 | 58.0 | 52.9 | 55.5 | 58.3 | 54.7 | 59.8 | 61.8 |
| | Min.... | 50.1 | 53.0 | 54.8 | 48.9 | 52.8 | 55.9 | 51.2 | 55.1 | 57.1 | 51.4 | 54.8 | 57.4 | 54.4 | 58.7 | 61.2 |
| 15 | Max.... | 57.4 | 56.4 | 56.2 | 57.0 | 56.7 | 56.8 | 56.9 | 55.7 | 56.4 | 57.2 | 55.8 | 56.6 | 56.5 | 57.9 | 60.3 |
| | Min.... | 52.9 | 53.8 | 54.9 | 51.2 | 53.8 | 55.8 | 52.9 | 54.8 | 56.1 | 53.1 | 54.6 | 56.3 | 54.3 | 57.4 | 59.6 |
| 16 | Max.... | 58.6 | 57.7 | 57.4 | 57.4 | 57.8 | 57.7 | 58.4 | 56.9 | 56.4 | 58.5 | 57.0 | 57.1 | 57.5 | 57.5 | 59.0 |
| | Min.... | 56.4 | 56.6 | 57.0 | 55.5 | 56.9 | 57.5 | 56.4 | 56.5 | 56.3 | 56.7 | 56.7 | 57.0 | 56.8 | 57.2 | 58.5 |
| 17 | Max.... | 58.1 | 57.8 | 57.6 | 57.5 | 57.9 | 57.8 | 58.1 | 57.1 | 56.9 | 58.4 | 57.1 | 57.7 | 57.5 | 57.4 | 58.3 |
| | Min.... | 52.9 | 55.8 | 56.6 | 51.7 | 55.5 | 57.1 | 54.1 | 56.4 | 56.8 | 54.2 | 56.2 | 57.2 | 56.3 | 57.2 | 58.1 |
| 19 | Max.... | 58.0 | 56.9 | 56.5 | 58.9 | 57.3 | 57.4 | 57.7 | 56.5 | 56.9 | 57.7 | 56.3 | 57.4 | 56.1 | 57.0 | 58.3 |
| | Min.... | 50.4 | 54.4 | 55.4 | 49.3 | 53.8 | 56.2 | 52.0 | 55.4 | 56.3 | 52.0 | 54.9 | 56.7 | 53.5 | 56.5 | 57.9 |
| 20 | Max.... | 60.6 | 57.9 | 57.0 | 61.2 | 58.8 | 57.1 | 59.7 | 56.4 | 56.5 | 60.0 | 56.5 | 56.6 | 57.5 | 57.2 | 57.9 |
| | Min.... | 51.6 | 54.5 | 55.4 | 50.5 | 54.3 | 56.1 | 52.6 | 55.4 | 56.0 | 52.9 | 54.9 | 56.4 | 54.0 | 56.1 | 57.6 |
| 21 | Max.... | 61.6 | 59.1 | 58.0 | 62.7 | 59.9 | 58.0 | 61.0 | 57.3 | 56.5 | 61.3 | 57.4 | 57.4 | 58.7 | 56.8 | 57.6 |
| | Min.... | 53.0 | 55.5 | 56.2 | 52.1 | 55.5 | 57.0 | 54.2 | 56.1 | 56.2 | 54.3 | 56.0 | 56.9 | 55.1 | 56.5 | 57.4 |
| 22 | Max.... | 61.7 | 59.0 | 57.9 | 61.7 | 59.6 | 58.1 | 60.7 | 57.6 | 57.0 | 60.9 | 57.6 | 57.9 | 58.4 | 57.2 | 57.8 |
| | Min.... | 53.4 | 55 9 | 56.8 | 52.3 | 55.8 | 57.3 | 54.6 | 56.7 | 56.7 | 54.8 | 56.6 | 57.4 | 55.5 | 56.9 | 57.6 |
| 23 | Max.... | 60.0 | 57.8 | 57.6 | 60.3 | 58.4 | 58.1 | 59.2 | 57.4 | 57.1 | 59.5 | 57.4 | 58.0 | 57.6 | 57.5 | 57.9 |
| | Min.... | 52.2 | 55.1 | 56.4 | 51.2 | 54.8 | 57.0 | 53.8 | 56.4 | 56.6 | 53.9 | 56.2 | 57.2 | 54.8 | 56.8 | 57.7 |
| 24 | Max.... | 53.9 | 55.9 | 57.1 | 53.1 | 56.1 | 57.6 | 54.4 | 56.5 | 56.9 | 54.8 | 56.9 | 57.6 | 55.9 | 57.2 | 57.9 |
| | Min.... | 52.3 | 54.0 | 56.0 | 51.9 | 54.8 | 56.8 | 53.4 | 55.9 | 56.6 | 53.7 | 55.8 | 57.2 | 54.8 | 56.9 | 57.7 |
| 26 | Max.... | 49.1 | 50.0 | 51.6 | 49.7 | 50.1 | 53.2 | 48.5 | 51.9 | 53.8 | 49.3 | 51.6 | 53.8 | 50.0 | 54.2 | 56.8 |
| | Min.... | 46.8 | 49.0 | 51.0 | 47.1 | 46.6 | 52.5 | 48.0 | 50.9 | 53.2 | 48.8 | 50.8 | 53.2 | 49.7 | 53.5 | 56.2 |
| 27 | Max.... | 43.3 | 44.1 | 48.8 | 45.3 | 47.6 | 49.8 | 43.8 | 48.9 | 52.2 | 44.1 | 49.4 | 51.3 | 48.5 | 52.8 | 55.6 |
| | Min.... | 40.2 | 42.4 | 47.1 | 43.7 | 46.3 | 48.4 | 40.4 | 47.7 | 51.0 | 41.1 | 47.2 | 50.5 | 45.4 | 51.6 | 54.8 |
| 28 | Max.... | 45.9 | 47.0 | 48.1 | 45.5 | 47.3 | 48.6 | 45.2 | 48.6 | 49.9 | 45.5 | 45.9 | 48.5 | 45.5 | 50.5 | 53.9 |
| | Min.... | 40.6 | 43.9 | 46.2 | 38.8 | 43.9 | 48.2 | 40.4 | 45.7 | 49.4 | 41.0 | 45.2 | 48.8 | 42 9 | 49.4 | 53.2 |
| 29 | Max.... | 45.5 | 47.3 | 48.6 | 44.1 | 48.4 | 48.8 | 45.7 | 47.6 | 48.8 | 47.3 | 47.6 | 48.9 | 46.2 | 48.9 | 52.4 |
| | Min.... | 44.8 | 46.4 | 47.5 | 43.4 | 46.4 | 47.1 | 45.5 | 46.9 | 48.7 | 45.3 | 47.2 | 48.3 | 45.4 | 48.6 | 51.8 |
| 30 | Max.... | 48.2 | 47.5 | 47.6 | 48.4 | 47.6 | 48.5 | 47.2 | 46.3 | 49.8 | 47.6 | 47.2 | 48.9 | 45.7 | 48.6 | 51.4 |
| | Min.... | 40.4 | 44.2 | 47.1 | 39.8 | 44.3 | 47.6 | 41.3 | 45.6 | 48.5 | 41.4 | 45.3 | 48.1 | 43.3 | 47.7 | 50.9 |
| 31 | Max.... | 50.2 | 48.6 | 48.9 | 50.7 | 49.1 | 48.9 | 48.8 | 46.9 | 48.3 | 49.6 | 47.2 | 48.4 | 46.4 | 47.7 | 50.5 |
| | Min.... | 41.0 | 44.8 | 46.4 | 40.7 | 44.9 | 47.5 | 43.6 | 45.9 | 48.0 | 43.2 | 45.6 | 48.2 | 43.5 | 47.5 | 50.2 |
| Ave. | Max.. | 58.71 | 57.76 | 57.74 | 58.60 | 57.80 | 57.81 | 58.08 | 57.22 | 57.34 | 58.37 | 57.06 | 57.97 | 57.78 | 58.17 | 59.21 |
| | Min.. | 52.96 | 55.18 | 56.36 | 52.05 | 55.05 | 56.90 | 53.79 | 56.21 | 56.84 | 53.86 | 55.90 | 57.23 | 55.52 | 57.42 | 58.86 |
| | Range | 5.75 | 2.58 | 1.38 | 6.55 | 2.75 | 0.91 | 4.29 | 1.01 | 0.50 | 4.51 | 1.16 | 0.74 | 2.26 | 0.75 | 0.35 |

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TABLE 62.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND, NOVEMBER, 1914.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ |
| 2 Max.... | 50.8 | 50.3 | 50.3 | 50.1 | 50.5 | 51.2 | 50.0 | 49.6 | 49.8 | 50.7 | 49.6 | 50.6 | 48.8 | 48.8 | 50.3 |
| 2 Min.... | 45.9 | 48.5 | 49 6 | 45.1 | 48.5 | 50.6 | 47.0 | 49.0 | 49.7 | 47.1 | 48.8 | 50.3 | 46.9 | 48.7 | 50.3 |
| 3 Max.... | 51.7 | 50.9 | 50.4 | 50.9 | 51.4 | 50.9 | 51.3 | 49.7 | 49.8 | 51.6 | 49.8 | 50.2 | 49.4 | 49.1 | 50.7 |
| 3 Min.... | 47.0 | 48.2 | 49.3 | 44.6 | 48.5 | 49.7 | 46.6 | 48.8 | 49.7 | 47.2 | 48.8 | 49.8 | 47.5 | 48.9 | 50.6 |
| 4 Max.... | 48.5 | 49.6 | 50.2 | 47.5 | 50.1 | 51.1 | 49.4 | 49.9 | 50.2 | 49.8 | 49.8 | 50.8 | 48.9 | 49.6 | 50.9 |
| 4 Min.... | 46.4 | 48.5 | 49.8 | 45.4 | 48.8 | 50.6 | 47.5 | 49.5 | 50.0 | 47.7 | 49.3 | 50.6 | 47.9 | 49.5 | 50.8 |
| 5 Max.... | 45.0 | 47.0 | 48.6 | 41.8 | 46.9 | 49.9 | 45.1 | 48.8 | 49.7 | 45.4 | 48.6 | 50.5 | 47.0 | 49.7 | 51.1 |
| 5 Min.... | 43.6 | 46.3 | 47.8 | 41.2 | 46.2 | 48.9 | 45.1 | 48.1 | 49.5 | 45.1 | 47.6 | 49.8 | 46.2 | 49.2 | 51.1 |
| 6 Max.... | 45.5 | 46.0 | 46.7 | 44.7 | 46.2 | 48.1 | 45.9 | 46.9 | 48.4 | 46.2 | 46.6 | 49.3 | 45.1 | 48.8 | 51.0 |
| 6 Min.... | 40.7 | 43.9 | 45.9 | 40.5 | 43.6 | 47.3 | 42.1 | 46.1 | 45.4 | 42.6 | 45.8 | 48.2 | 43 6 | 48.0 | 50 6 |
| 7 Max.... | 49.4 | 48.0 | 47.5 | 48.5 | 48.3 | 48.0 | 48.9 | 46.6 | 47.9 | 49.3 | 47.1 | 48.1 | 46.5 | 47.8 | 50.3 |
| 7 Min.... | 42.7 | 44.7 | 45.9 | 40.8 | 44.7 | 47.1 | 43.3 | 45.8 | 47.5 | 43.4 | 45.7 | 47.8 | 44.1 | 47.3 | 49.8 |
| 9 Max .... | 41.6 | 41.7 | 44.4 | 40.0 | 43.4 | 46.1 | 41.5 | 44.7 | 47.4 | 41.7 | 45.4 | 47.5 | 43.7 | 47.5 | 49.5 |
| 9 Min.... | 37.1 | 40.7 | 43.3 | 35.6 | 40.6 | 45.0 | 38.3 | 43.5 | 46.2 | 38.8 | 43.3 | 46.0 | 41.2 | 46.1 | 48.8 |
| 10 Max.... | 43.0 | 43.1 | 43.6 | 41.2 | 43.4 | 45.0 | 42.2 | 43.2 | 45.4 | 42.7 | 43.3 | 45.6 | 41.6 | 45.5 | 48.6 |
| 10 Min.... | 39.4 | 41.7 | 43.2 | 37.2 | 41.6 | 44.7 | 39.3 | 42.9 | 45.2 | 40.4 | 42.8 | 45.4 | 40.4 | 45.1 | 48.0 |
| 11 Max.... | 43.0 | 43.1 | 43.4 | 41.1 | 43.3 | 45.0 | 42.3 | 43.1 | 45.1 | 43.1 | 43.2 | 45.4 | 41.3 | 45.4 | 47.6 |
| 11 Min.... | 38.0 | 41.0 | 43.0 | 39.3 | 41.2 | 44.5 | 39.3 | 42.6 | 44.8 | 40.3 | 42.5 | 45.1 | 40.3 | 44.4 | 47.3 |
| 12 Max.... | 40.3 | 41.6 | 42.9 | 36.6 | 41.6 | 44.4 | 40.3 | 42.8 | 44.8 | 40.7 | 42.7 | 45.1 | 40.5 | 44.1 | 47.0 |
| 12 Min.. | 38.6 | 40.8 | 42.4 | 35.8 | 40.8 | 44.0 | 39.1 | 42.3 | 44.4 | 39.4 | 42.1 | 44.4 | 40.0 | 43.8 | 46.7 |
| 13 Max.... | 43.0 | 43.1 | 43.9 | 39.4 | 43.6 | 45.1 | 41.8 | 43.2 | 44.4 | 42.5 | 43.3 | 44.7 | 41.7 | 43.5 | 46.4 |
| 13 Min.... | 41.3 | 42.6 | 43.1 | 37.6 | 42.8 | 44.4 | 41.8 | 42.5 | 44.1 | 42.3 | 42.5 | 44.4 | 40.8 | 43.5 | 46.2 |
| 14 Max.... | 41.9 | 42.4 | 42.9 | 39.7 | 42.5 | 44.4 | 41.5 | 42.6 | 44.4 | 42.1 | 42.5 | 44.8 | 40.6 | 43.5 | 46.1 |
| 14 Min.... | 37.7 | 40.4 | 42.3 | 36.9 | 40.4 | 43.8 | 38.9 | 41.9 | 44.2 | 39.4 | 41.8 | 44.1 | 39.5 | 43.2 | 45 8 |
| 16 Max.... | 38.9 | 42.6 | 44.4 | 38.6 | 42.6 | 45.5 | 40.0 | 43.9 | 44.8 | 40.5 | 43.9 | 45.4 | 42.4 | 43.9 | 45.8 |
| 16 Min.... | 37.3 | 40.7 | 42.6 | 36.5 | 40.6 | 44.1 | 38.1 | 42.4 | 44.6 | 38.6 | 42.3 | 44.9 | 39.5 | 43.6 | 45.7 |
| 17 Max.... | 36.3 | 39.4 | 41.3 | 35.5 | 39.4 | 42.9 | 37.0 | 41.4 | 44.2 | 37.1 | 41.1 | 43.5 | 39.3 | 43.4 | 45.8 |
| 17 Min.... | 35 4 | 38.5 | 40.3 | 34.8 | 38.7 | 42.1 | 36.1 | 40.6 | 43.4 | 36.3 | 40.4 | 43.1 | 38 6 | 42.8 | 45 6 |
| 18 Max.... | 33.9 | 37.4 | 39.4 | 33.4 | 37.5 | 41.2 | 34.9 | 39.7 | 42.5 | 35.0 | 39.0 | 42.3 | 37.5 | 42.3 | 45.4 |
| 18 Min.... | 33 5 | 36.6 | 38 5 | 33.1 | 36 8 | 40.5 | 34.4 | 38.7 | 42.3 | 34.5 | 38.2 | 41.4 | 36.8 | 41 6 | 45.1 |
| 19 Max .... | 33.9 | 36.6 | 38.2 | 33.5 | 36.8 | 40.0 | 34.4 | 38.3 | 41.3 | 34.6 | 37.9 | 40.9 | 36.2 | 41.0 | 44.5 |
| 19 Min .... | 33.7 | 36.4 | 38 0 | 33.4 | 36.7 | 39.8 | 34.3 | 37.9 | 41.0 | 34.5 | 37.6 | 40.6 | 36.2 | 40.7 | 44 2 |
| 20 Max.... | 33.9 | 36.4 | 37.9 | 33.3 | 36.5 | 39.7 | 34.2 | 37.8 | 40.6 | 34.6 | 37.4 | 40.3 | 35.8 | 40.2 | 43.5 |
| 20 Min.... | 33.8 | 36.3 | 37.7 | 33 2 | 36.3 | 39.4 | 34.0 | 37 5 | 40.4 | 34.4 | 37.2 | 40.0 | 35.6 | 39.8 | 43.3 |
| 21 Max.... | 33.8 | 36.3 | 37.7 | 33.2 | 36.3 | 39.3 | 34.0 | 37.4 | 39.9 | 34.5 | 37.2 | 39.8 | 35.2 | 39.5 | 42.8 |
| 21 Min.... | 33.6 | 36.1 | 37.4 | 33 0 | 36.0 | 39.1 | 33.9 | 37.2 | 39.7 | 34.3 | 36.9 | 39.5 | 35.1 | 39.3 | 42 4 |
| 23 Max.... | 32.9 | 35.7 | 37.3 | 32.2 | 35.8 | 38.9 | 33.9 | 37.0 | 39.4 | 34.3 | 36.9 | 39.3 | 35.0 | 38.5 | 41.7 |
| 23 Min.... | 32.3 | 35.1 | 36.7 | 31.6 | 35.1 | 38.3 | 33.4 | 36.7 | 39.1 | 33.8 | 36.5 | 39.0 | 34.1 | 38.1 | 41.3 |
| 24 Max.... | 32.2 | 34.8 | 36.4 | 32.0 | 34.8 | 38.0 | 33.4 | 36.5 | 38.9 | 33.7 | 36.4 | 38.8 | 34.4 | 37.9 | 41.1 |
| 24 Min.... | 32 1 | 34 6 | 36.3 | 31.3 | 34.8 | 37.9 | 33 3 | 36.4 | 38.5 | 33.5 | 36.2 | 38.4 | 34.2 | 37.8 | 40 8 |
| 25 Max.... | 32.7 | 34.9 | 36.3 | 32.3 | 35.0 | 37.9 | 33.4 | 36.3 | 38.4 | 33.9 | 36.2 | 38.4 | 34.3 | 37.7 | 40.7 |
| 25 Min.... | 32.4 | 34.8 | 36.2 | 32.2 | 34.8 | 37.7 | 33.3 | 36.1 | 38.2 | 33.8 | 36.1 | 38.2 | 34.2 | 37.4 | 40.6 |
| 26 Max.... | 41.9 | 39.2 | 38.1 | 41.6 | 39.0 | 38.7 | 39.3 | 36.8 | 38.2 | 40.9 | 37.6 | 38.3 | 34.2 | 37.4 | 40.5 |
| 26 Min.... | 33.2 | 34.9 | 36.3 | 32.6 | 35.2 | 37.7 | 33.4 | 36.0 | 38.0 | 34.0 | 36.2 | 38.1 | 34.0 | 37.2 | 40.1 |
| 27 Max.... | 38.5 | 40.2 | 40.4 | 38.0 | 40.4 | 40.9 | 38.7 | 39.2 | 39.7 | 39.7 | 39.9 | 40.5 | 35.2 | 37.3 | 40.2 |
| 27 Min.... | 37.4 | 39.1 | 39.9 | 37.3 | 39.4 | 40.8 | 37.9 | 38.9 | 38.9 | 38.9 | 39.8 | 39.9 | 34.4 | 37.3 | 40.0 |
| 28 Max.... | 35.2 | 37.9 | 39.4 | 34.6 | 37.9 | 40.4 | 35.9 | 38.8 | 40.2 | 36.4 | 39.2 | 40.9 | 35.3 | 37.6 | 40.4 |
| 28 Min.... | 34.2 | 37.2 | 38.3 | 33.9 | 37.2 | 39.6 | 34.8 | 37.9 | 39.9 | 35.2 | 37 9 | 40.2 | 35.0 | 37.4 | 40 3 |
| 30 Max.... | 46.3 | 44.1 | 42.7 | 46.7 | 44.5 | 42.8 | 44.9 | 41.5 | 40.4 | 45.8 | 41.9 | 41.1 | 41.1 | 38.3 | 40.4 |
| 30 Min.... | 42.7 | 41.2 | 40 7 | 42.6 | 41.6 | 41.2 | 41.3 | 39.4 | 39.6 | 42.0 | 39.9 | 40.0 | 37.9 | 37.7 | 40.3 |
| Ave. Max | 40.56 | 41.69 | 42.57 | 39.50 | 41.90 | 43.82 | 40.57 | 42.23 | 43.84 | 41.08 | 42.26 | 44.09 | 40.44 | 43.13 | 46.85 |
| Ave. Min | 38.00 | 40.36 | 41.78 | 37.06 | 40.44 | 43.15 | 38.68 | 41.55 | 43.37 | 39.10 | 41.45 | 43.57 | 39.36 | 42.74 | 45.43 |
| Ave. Range | 2.56 | 1.33 | 0.79 | 2.44 | 1.46 | 0.67 | 1.89 | 0.68 | 0.47 | 1.98 | 0.81 | 0.52 | 1.08 | 0.39 | 0.42 |

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BEGINNING WITH FOURTH YEAR.

TABLE 63.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, DECEMBER, 1914.

| Date— Maximum, minimum. | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 2 | Max.... | 47.4 | 47.3 | 46.9 | 46.2 | 47.1 | 47.1 | 46.9 | 46.6 | 45.4 | 47.3 | 46.6 | 46.2 | 46.3 | 45.4 | 45.5 |
| | Min.... | 44.6 | 45.4 | 46.1 | 44.4 | 45.2 | 46.1 | 44.9 | 45.4 | 45.2 | 45.3 | 45.8 | 46.1 | 45.4 | 45.4 | 45.3 |
| 3 | Max.... | 42.5 | 41.8 | 41.4 | 39.7 | 39.8 | 40.4 | 40.4 | 41.1 | 41.5 | 42.4 | 41.4 | 42.1 | 40.9 | 42.2 | 44.1 |
| | Min.... | 36.5 | 38.4 | 40.4 | 36.2 | 37.8 | 40.0 | 37.4 | 40 3 | 40.8 | 37.4 | 40.3 | 41.5 | 39.6 | 41.2 | 42.9 |
| 4 | Max.... | 37.9 | 37.7 | 38.1 | 37.4 | 37.4 | 38.1 | 37.3 | 37.7 | 38.1 | 37.5 | 37.6 | 38.7 | 37.4 | 38.8 | 41.1 |
| | Min.... | 33.4 | 35.1 | 37.0 | 33.7 | 35.0 | 36.8 | 33.9 | 36.7 | 37.5 | 34.5 | 36.6 | 38.0 | 36.7 | 38.2 | 40.4 |
| 5 | Max.... | 38.6 | 38.0 | 38.4 | 38.1 | 38.1 | 38.8 | 37.5 | 38.0 | 37.9 | 38.0 | 38.0 | 38.4 | 37.7 | 38.2 | 39.4 |
| | Min.... | 34.0 | 35.2 | 36.4 | 34.0 | 35.0 | 36.3 | 34.1 | 35.9 | 36.8 | 35.7 | 35.9 | 37.1 | 35.7 | 37.3 | 39.1 |
| 7 | Max.... | 34.8 | 35.1 | 35.5 | 34.0 | 34.7 | 35.4 | 34.1 | 34.9 | 35.4 | 34.7 | 35.0 | 35.9 | 35.0 | 36.3 | 37.9 |
| | Min.... | 33.2 | 34.2 | 35.2 | 33.1 | 34.0 | 35.3 | 33.4 | 34.8 | 35 3 | 33.8 | 34.9 | 35.8 | 34.8 | 35.9 | 37.5 |
| 8 | Max.... | 33.0 | 34.0 | 34.7 | 32.8 | 33.6 | 34.5 | 32.8 | 33.9 | 34.4 | 33.4 | 33.9 | 34.7 | 33.8 | 35.0 | 37.0 |
| | Min.... | 32.1 | 33.3 | 34.1 | 32.3 | 33.4 | 34.3 | 32.4 | 33.8 | 34.2 | 32.6 | 33.6 | 34.5 | 33.5 | 34.7 | 36.5 |
| 9 | Max.... | 32.4 | 33.4 | 34.2 | 32.4 | 33.4 | 34.3 | 32.4 | 33.7 | 34.1 | 32.8 | 33.5 | 34.4 | 33.5 | 34.4 | 36.3 |
| | Min.... | 32.3 | 33.2 | 34.0 | 31.9 | 33.2 | 34.1 | 32.4 | 33.6 | 34.0 | 32.5 | 33.3 | 34.2 | 33.3 | 34.2 | 35.9 |
| 10 | Max.... | 32.2 | 33.2 | 33.9 | 32.1 | 33.0 | 33.8 | 32.4 | 33.5 | 33.9 | 32.4 | 33.1 | 33.9 | 33.1 | 33.9 | 35.7 |
| | Min.... | 31.9 | 33.0 | 33.8 | 31.4 | 32.8 | 33.7 | 32.4 | 33.5 | 33.7 | 32.2 | 33.0 | 33.8 | 33.1 | 33.9 | 35.4 |
| 11 | Max.... | 31.5 | 32.6 | 33.5 | 30.4 | 32.1 | 33.2 | 32.2 | 33.4 | 33.8 | 31.4 | 32.7 | 33.5 | 33.0 | 33.8 | 35.5 |
| | Min.... | 29.4 | 32.2 | 33.1 | 26.1 | 30.6 | 32.4 | 32.0 | 33.1 | 33.4 | 31.0 | 32.2 | 33.2 | 32.4 | 33.4 | 35.0 |
| 12 | Max.... | 30.7 | 31.9 | 32.6 | 29.7 | 30.7 | 32.1 | 31.6 | 32.9 | 33.2 | 30.5 | 31.6 | 32.6 | 32.4 | 33.4 | 34.9 |
| | Min.... | 29.8 | 31.4 | 32.5 | 27.5 | 29.7 | 31.8 | 31.5 | 32.8 | 33.0 | 29.7 | 31.5 | 32.4 | 32.2 | 33.2 | 34.6 |
| 14 | Max.... | 31.2 | 32.2 | 32.9 | 27.0 | 29.6 | 32.0 | 31.7 | 32.9 | 33.4 | 31.5 | 32.2 | 32.8 | 32.4 | 33.1 | 34.5 |
| | Min.... | 28.4 | 32.1 | 32.6 | 21.8 | 26.3 | 30.0 | 30.0 | 32.6 | 33.0 | 29.3 | 31.5 | 32.6 | 32.1 | 32.9 | 34.4 |
| 15 | Max.... | 29.3 | 30.5 | 31.5 | 25.1 | 27.0 | 28.9 | 30.4 | 32.2 | 32.7 | 29.0 | 30.3 | 32.0 | 31.5 | 32.8 | 34.2 |
| | Min.... | 27.7 | 29.7 | 31.1 | 21.8 | 24.6 | 27.4 | 29.9 | 32.0 | 32.4 | 27.4 | 29.8 | 31.4 | 31.1 | 32.6 | 34.1 |
| 16 | Max.... | 29.2 | 30.2 | 31.2 | 23.4 | 26.1 | 28.4 | 30.1 | 31.9 | 32.6 | 28.5 | 29.9 | 31.4 | 31.3 | 32.5 | 34.0 |
| | Min.... | 27.9 | 29.8 | 30 9 | 20.4 | 24.1 | 26.9 | 29.6 | 31.6 | 32.3 | 27.6 | 29.5 | 30.9 | 31.1 | 32.4 | 33.9 |
| 17 | Max.... | 29.4 | 30.2 | 30.8 | 25.3 | 26.4 | 27.8 | 30.0 | 31.5 | 33.4 | 28.8 | 29.6 | 30.9 | 31.3 | 32.4 | 33.8 |
| | Min.... | 27.6 | 29.7 | 30.6 | 21 0 | 24.6 | 26.9 | 29.3 | 31.4 | 32.1 | 27 6 | 29.4 | 30.8 | 30.8 | 32.3 | 33.6 |
| 18 | Max.... | 30.0 | 30.8 | 31.1 | 27.5 | 28.8 | 29.7 | 30.2 | 31.3 | 32.0 | 29.5 | 30.0 | 30.7 | 31.4 | 32.2 | 33.6 |
| | Min.... | 27.5 | 28.9 | 30.0 | 21.5 | 23.3 | 25.3 | 29.0 | 31.0 | 31.6 | 27.3 | 28.8 | 30.3 | 30.6 | 32.0 | 33.4 |
| 19 | Max.... | 31.2 | 31.8 | 32.0 | 30.1 | 31.2 | 31.6 | 31.0 | 31.7 | 31.8 | 30.8 | 31.1 | 31.4 | 31.9 | 32.0 | 33.4 |
| | Min.... | 30.9 | 31.4 | 31.6 | 29.6 | 30.6 | 30.9 | 30.7 | 31.5 | 31.6 | 30.4 | 30 6 | 31.1 | 31.8 | 32.0 | 33.3 |
| 21 | Max.... | 31.4 | 31.9 | 32.1 | 29.4 | 31.0 | 31.5 | 31.0 | 31.8 | 31.9 | 31.1 | 31.3 | 31.7 | 31.9 | 32.1 | 33.3 |
| | Min.... | 31.0 | 31.5 | 31.9 | 29.3 | 30.4 | 31.0 | 30.9 | 31.7 | 31.7 | 30.9 | 31.1 | 31.6 | 31.6 | 31.9 | 33.2 |
| 22 | Max.... | 31.2 | 31.9 | 32.1 | 29.3 | 30.1 | 30.9 | 30.8 | 31.8 | 32.0 | 31.1 | 31.4 | 32.0 | 31.7 | 32.2 | 33.3 |
| | Min.... | 31.1 | 31.6 | 32.0 | 28.8 | 29.9 | 30.7 | 30.6 | 31.6 | 31.8 | 30.9 | 31 1 | 31.8 | 31.5 | 32.0 | 33.2 |
| 23 | Max.... | 31.3 | 31.9 | 32.2 | 29.3 | 30.5 | 31.2 | 30.8 | 31.7 | 32.0 | 31.0 | 31.4 | 31.9 | 31.6 | 32.1 | 33.3 |
| | Min.... | 31.2 | 31.8 | 32.1 | 29.0 | 30.1 | 31.0 | 30.6 | 31.5 | 31.8 | 30.8 | 31 3 | 31.8 | 31.4 | 32.0 | 33.1 |
| 24 | Max.... | 31.5 | 32.1 | 32.3 | 29.2 | 30.9 | 31.6 | 31.0 | 31.7 | 31.9 | 31.2 | 31.4 | 32.0 | 31.7 | 32.1 | 33.4 |
| | Min.... | 31.2 | 31.9 | 32.2 | 28.6 | 30.3 | 31.0 | 30.7 | 31.6 | 31.7 | 30.9 | 31.3 | 31.8 | 31.5 | 32.0 | 33.1 |
| 26 | Max.... | 30.8 | 31.6 | 32.2 | 27.4 | 28.9 | 30.3 | 30.4 | 31.8 | 32.9 | 30.5 | 31.4 | 32.1 | 31.2 | 32.2 | 33.4 |
| | Min.... | 30.2 | 31 1 | 31.7 | 26.1 | 28.1 | 29.6 | 29.8 | 31.1 | 31.5 | 30.0 | 30.7 | 31.4 | 30.6 | 31.6 | 32 9 |
| 28 | Max.... | 31.5 | 32.0 | 32.1 | 29.9 | 31.3 | 31.6 | 30.8 | 31.5 | 31.6 | 31.2 | 31.3 | 31.7 | 31.6 | 31.7 | 32.7 |
| | Min.... | 31.4 | 31.9 | 32.1 | 29.0 | 30.7 | 31.3 | 30.7 | 31.5 | 31.5 | 31.0 | 31.3 | 31.6 | 31.4 | 31.6 | 32.6 |
| 29 | Max.... | 31.9 | 32.3 | 32.3 | 31.0 | 31.8 | 32.1 | 31.2 | 31.7 | 31.7 | 31.6 | 31.5 | 31.9 | 32.0 | 31.8 | 32.6 |
| | Min.... | 31.7 | 32.1 | 32.2 | 30.5 | 31.6 | 31.9 | 31.0 | 31.6 | 31.6 | 31.4 | 31 5 | 31.8 | 31.8 | 31.6 | 32 6 |
| 30 | Max.... | 32.2 | 32.4 | 32.4 | 31.6 | 32.2 | 32.4 | 31.4 | 32.0 | 31.9 | 31.9 | 31.9 | 32.1 | 32.1 | 31.9 | 32.8 |
| | Min.... | 32.0 | 32.3 | 32.3 | 31.5 | 32 1 | 32 3 | 31.3 | 31 9 | 31 7 | 31.7 | 31.8 | 32.0 | 32.0 | 31.8 | 32.6 |
| 31 | Max.... | 32.1 | 32.5 | 32.5 | 30.9 | 31.8 | 32.4 | 31.4 | 32.2 | 32.0 | 31.8 | 32.1 | 32.3 | 32.0 | 32.0 | 32.9 |
| | Min.... | 31.8 | 32 3 | 32.4 | 30 5 | 31 4 | 32.0 | 31.2 | 32.0 | 31.9 | 31.5 | 31.8 | 32.1 | 31.5 | 31.9 | 32.7 |
| Ave. | Max.. | 33.02 | 33.57 | 33.96 | 31.58 | 32.31 | 33.36 | 32.78 | 33.74 | 34.06 | 32.80 | 33.21 | 33.89 | 33.55 | 34.18 | 35.55 |
| | Min.. | 31.55 | 32.78 | 33.53 | 29.20 | 30.99 | 32.76 | 31.99 | 33.38 | 33.89 | 31.74 | 32.75 | 33.59 | 33.10 | 33.92 | 35.25 |
| | Range | 1.47 | 0.79 | 0.43 | 2.38 | 1.32 | 0.60 | 0.80 | 0.36 | 0.37 | 1.06 | 0.46 | 0.30 | 0.45 | 0.26 | 0.30 |

TABLE 64.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JANUARY, 1915.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 2 | Max.... | 32.2 | 32.4 | 32.5 | 31.5 | 32.2 | 32.4 | 31.4 | 32.1 | 31.9 | 32.0 | 32.0 | 32.3 | 31.9 | 31.9 | 32.8 |
| | Min.... | 32.1 | 32.4 | 32.4 | 31.4 | 32.0 | 32.3 | 31.3 | 32.0 | 31.9 | 31.9 | 31.9 | 32.1 | 31.9 | 31.7 | 32 6 |
| 4 | Max.... | 31.8 | 32.3 | 32.5 | 31.1 | 31.6 | 32.2 | 31.0 | 31.9 | 31.9 | 31.4 | 31.8 | 32.2 | 31.3 | 31.7 | 32.6 |
| | Min.... | 31.7 | 32.3 | 32.3 | 30.7 | 31.5 | 32.1 | 30.9 | 31.6 | 31.5 | 31.4 | 31.3 | 32.0 | 31.3 | 31.4 | 32 4 |
| 5 | Max.... | 32.1 | 32.3 | 32.4 | 31.5 | 32.1 | 32.3 | 31.2 | 31.2 | 31.7 | 31.7 | 31.8 | 32.2 | 31.7 | 31.6 | 32.4 |
| | Min.... | 31.9 | 32.3 | 32.3 | 31.4 | 31.9 | 32.2 | 31.1 | 31.6 | 31 5 | 31.6 | 31.0 | 32.0 | 31.5 | 31.5 | 32.3 |
| 6 | Max.... | 32.2 | 32.3 | 32.4 | 31.9 | 32.2 | 32.3 | 31.4 | 32.1 | 31.7 | 32.4 | 32.3 | 32.3 | 32.2 | 31.8 | 32.4 |
| | Min.... | 32.1 | 32.3 | 32.3 | 31.7 | 32.1 | 32.3 | 31.3 | 31.8 | 31.6 | 31.9 | 31.8 | 32.1 | 31.9 | 31.5 | 32.3 |
| 7 | Max.... | 32.3 | 32.5 | 32.5 | 32.1 | 32.4 | 32.4 | 31.8 | 32.1 | 31.9 | 32.5 | 32.3 | 32.3 | 32.4 | 32.0 | 32.4 |
| | Min.... | 32.2 | 32.4 | 32.4 | 32.1 | 32.3 | 32.4 | 31 8 | 32.1 | 31.8 | 32.4 | 32.3 | 32.3 | 32.3 | 31.9 | 32.3 |
| 8 | Max.... | 32.4 | 32.6 | 32.7 | 32.2 | 32.4 | 32.5 | 32.0 | 32.2 | 32.0 | 32.5 | 32.4 | 32.3 | 32.3 | 32.1 | 32.5 |
| | Min.... | 32.3 | 32.4 | 32.6 | 32.1 | 32.3 | 32.4 | 31.9 | 32.2 | 31.9 | 32.5 | 32.3 | 32.3 | 32.3 | 32.0 | 32.4 |
| 9 | Max.... | 32.4 | 32.6 | 32.9 | 31.9 | 32.5 | 32.6 | 32.0 | 32.3 | 32.1 | 32.6 | 32.4 | 32.4 | 32.5 | 32.1 | 32.6 |
| | Min.... | 32.3 | 32.6 | 32.8 | 31.8 | 32.3 | 32.5 | 31.8 | 32.2 | 32.0 | 32.5 | 32.4 | 32.3 | 32.4 | 32.0 | 32.5 |
| 11 | Max.... | 32.2 | 32.6 | 32.8 | 31.9 | 32.3 | 32.6 | 31.5 | 32.2 | 32.0 | 32.2 | 32.3 | 32.3 | 32.3 | 32.0 | 32.5 |
| | Min.... | 32.2 | 32.5 | 32.8 | 31.8 | 32.2 | 32.6 | 31.5 | 32.1 | 32.0 | 32.1 | 32.2 | 32.3 | 32 3 | 31.9 | 32.4 |
| 12 | Max.... | 32.3 | 32.8 | 33.1 | 32.0 | 32.5 | 32.7 | 31.8 | 32.3 | 32.1 | 32.4 | 32.3 | 32.5 | 32.3 | 32.0 | 32.6 |
| | Min.... | 32.3 | 32 7 | 33.0 | 31.9 | 32.3 | 32.6 | 31.7 | 32.2 | 32.0 | 32.3 | 32.3 | 32.4 | 32.3 | 31.9 | 32.5 |
| 13 | Max.... | 32.3 | 32.9 | 33.1 | 32.1 | 32.4 | 32.8 | 31.9 | 32.2 | 32.1 | 32.3 | 32.3 | 32.5 | 32.3 | 32.1 | 32.6 |
| | Min.... | 32.3 | 32.7 | 33.0 | 31.8 | 32.3 | 32.7 | 31.6 | 32 2 | 32.0 | 32.3 | 32.3 | 32.4 | 32.3 | 32.0 | 32.5 |
| 14 | Max.... | 32.3 | 32.8 | 33.1 | 31.8 | 32.4 | 32.9 | 31.5 | 32.3 | 32.1 | 32.3 | 32.3 | 32.6 | 32.3 | 31.9 | 32.6 |
| | Min.... | 32.3 | 32.7 | 33.0 | 31.6 | 32.3 | 32.8 | 31.4 | 32.1 | 32.0 | 32.1 | 32.3 | 32.5 | 32.3 | 31.8 | 32.5 |
| 15 | Max.... | 32.3 | 32.9 | 33.2 | 31.8 | 32.4 | 32.9 | 31.7 | 32.2 | 32.1 | 32.3 | 32.3 | 32.7 | 32.3 | 32.0 | 32.6 |
| | Min.... | 32.3 | 32.7 | 33.1 | 31.3 | 32.3 | 32.8 | 31.5 | 32.1 | 32.0 | 32.2 | 32.2 | 32.5 | 32.3 | 31.9 | 32.5 |
| 16 | Max.... | 32.4 | 32.9 | 33.2 | 31.1 | 32.4 | 33.0 | 31.6 | 32.2 | 32.1 | 32.3 | 32.3 | 32.6 | 32.3 | 32.1 | 32.6 |
| | Min.... | 32.3 | 32.8 | 33.1 | 30.9 | 32.3 | 32.9 | 31.4 | 32.1 | 32.0 | 32.1 | 32:3 | 32.6 | 32.3 | 31.9 | 32.5 |
| 18 | Max.... | 32.4 | 32.9 | 33.2 | 32.2 | 32.6 | 32.9 | 32.0 | 32.3 | 32.2 | 32.5 | 32.4 | 32.7 | 32.3 | 32.1 | 32.5 |
| | Min.... | 32.3 | 32.8 | 33.1 | 32.0 | 32.5 | 32.8 | 31.9 | 32.3 | 32.1 | 32.4 | 32.4 | 32.6 | 32.3 | 32.0 | 32.4 |
| 19 | Max.... | 32.4 | 32.9 | 33.2 | 32.1 | 32.6 | 33.1 | 31.9 | 32.3 | 32.2 | 32.3 | 32.4 | 32.8 | 32.3 | 32.0 | 32.5 |
| | Min.... | 32.4 | 32.8 | 33.1 | 32.1 | 32.5 | 32.9 | 31.9 | 32.2 | 32.1 | 32.3 | 32.4 | 32.7 | 32.3 | 31.9 | 32.4 |
| 20 | Max.... | 32.3 | 32.9 | 33.2 | 32.1 | 32.6 | 33.1 | 31.9 | 32.4 | 32.3 | 32.2 | 32.4 | 32.9 | 32.4 | 32.1 | 32.6 |
| | Min.... | 32 3 | 32.8 | 33.1 | 32.1 | 32.4 | 32.8 | 31.6 | 32 3 | 32.2 | 32.2 | 32.4 | 32.8 | 32.3 | 31.9 | 32.4 |
| 21 | Max .... | 32.3 | 32.9 | 33.2 | 31.7 | 32.3 | 33.1 | 31.6 | 32.3 | 32.3 | 32.2 | 32.4 | 32.9 | 32.4 | 32.1 | 32.7 |
| | Min .... | 32.3 | 32 6 | 33.1 | 31.4 | 32.2 | 32 7 | 31.5 | 32 3 | 32.2 | 32.1 | 32.2 | 32.9 | 32.3 | 32.0 | 32.6 |
| 22 | Max.... | 32.2 | 32.9 | 33.3 | 30.4 | 31.4 | 32.7 | 31.5 | 32.4 | 32.4 | 31.9 | 32.4 | 33.0 | 32.5 | 32.2 | 32.9 |
| | Min.... | 32.1 | 32.8 | 33.1 | 30.3 | 31.3 | 32.6 | 31.3 | 32.3 | 32 3 | 31.8 | 32 3 | 32.9 | 32.4 | 32.1 | 32 7 |
| 23 | Max.... | 32.2 | 32.6 | 33.1 | 30.6 | 31.0 | 32.4 | 31.4 | 32.3 | 32.3 | 32.1 | 32.3 | 32.7 | 32.4 | 32.2 | 32.8 |
| | Min.... | 32.0 | 32.5 | 32.9 | 29.9 | 30.8 | 32.2 | 31.3 | 32.2 | 32.3 | 32.0 | 32.2 | 32.6 | 32.3 | 32.0 | 32.7 |
| 25 | Max .... | 31.5 | 32.1 | 32.5 | 29.8 | 30.4 | 31.1 | 31.1 | 32.1 | 32.2 | 31.6 | 32.0 | 32.6 | 32.1 | 32.1 | 32.8 |
| | Min.... | 31.1 | 31.8 | 32.4 | 28.8 | 29.7 | 31.0 | 30.9 | 32.0 | 32.1 | 31.4 | 31.9 | 32 4 | 31.9 | 32.0 | 32.6 |
| 26 | Max.... | 31.2 | 32.0 | 32.5 | 29.2 | 30.0 | 31.0 | 30.9 | 32.1 | 32.3 | 31.4 | 32.0 | 32.6 | 32.1 | 32.2 | 32.9 |
| | Min.... | 30.7 | 31.5 | 32.3 | 28.0 | 29.6 | 30.4 | 30.5 | 31.9 | 32.0 | 31.1 | 31.5 | 32.3 | 31.7 | 32.0 | 32.6 |
| 27 | Max.... | 31.2 | 31.6 | 32.2 | 28.9 | 29.6 | 30.5 | 30.9 | 32.0 | 32.2 | 31.3 | 31.8 | 32.5 | 31.8 | 32.1 | 32.8 |
| | Min.... | 30.4 | 31.2 | 32.0 | 26.7 | 28.0 | 29.8 | 30.4 | 31.8 | 32.0 | 31.0 | 31.5 | 32.3 | 31.5 | 31.8 | 32.7 |
| 28 | Max.... | 30.7 | 31.4 | 32.3 | 28.0 | 29.0 | 30.4 | 30.6 | 32.0 | 32.2 | 31.2 | 31.9 | 32.6 | 32.0 | 32.2 | 33.1 |
| | Min.... | 30.2 | 31.0 | 31.8 | 27.0 | 28.1 | 29.7 | 30.3 | 31.5 | 31.8 | 30.7 | 31.4 | 32.3 | 31.4 | 31.8 | 32.8 |
| 29 | Max.... | 30.5 | 31.2 | 31.8 | 27.8 | 28.7 | 29.8 | 30.4 | 31.6 | 32.0 | 30.8 | 31.4 | 32.4 | 31.5 | 32.0 | 32.9 |
| | Min.... | 30.2 | 30.8 | 31.5 | 26.9 | 28.0 | 29.4 | 30.3 | 31.4 | 31.8 | 30.6 | 31.2 | 32.2 | 31.4 | 31.8 | 32.7 |
| 30 | Max.... | 29.6 | 30.2 | 31.3 | 25.9 | 26.8 | 28.1 | 29.8 | 31.4 | 32.1 | 30.4 | 31.4 | 32.4 | 31.1 | 32.0 | 33.2 |
| | Min.... | 28.6 | 29.5 | 30.5 | 23.9 | 25.1 | 27.1 | 29.2 | 30 8 | 31.4 | 29.8 | 30.5 | 32 0 | 30.5 | 31.3 | 32.6 |
| Ave. | Max. | 31.91 | 32.38 | 32.73 | 30.86 | 31.47 | 32.07 | 31.39 | 32.13 | 32.10 | 31.95 | 32.15 | 32.53 | 32.12 | 32.03 | 32.88 |
| | Min. | 31.72 | 32.20 | 32.56 | 30.38 | 31.13 | 31.84 | 31.21 | 31.97 | 31.94 | 31.79 | 31.94 | 32.39 | 31.99 | 31.84 | 32.52 |
| | Range | 0.19 | 0.18 | 0.17 | 0.48 | 0.34 | 0.23 | 0.18 | 0.16 | 0.16 | 0.16 | 0.21 | 0.14 | 0.13 | 0.19 | 0.16 |

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TABLE 65.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, FEBRUARY, 1915.

| Date— Maximum, minimum. | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 | Max.... | 32.2 | 32.2 | 32.3 | 32.2 | 32.4 | 32.5 | 31.4 | 31.8 | 31.6 | 32.2 | 32.0 | 32.2 | 32.2 | 31.9 | 32.5 |
| | Min.... | 32.0 | 32.1 | 32.1 | 32.1 | 32.3 | 32.4 | 31.1 | 31 5 | 31.4 | 31.9 | 31.6 | 32.0 | 32.1 | 31.6 | 32.4 |
| 2 | Max.... | 32.3 | 32.4 | 32.4 | 32.3 | 32.4 | 32.6 | 31.6 | 32.1 | 31.7 | 32.1 | 32.1 | 32.3 | 32.3 | 32.0 | 32.5 |
| | Min.... | 32.3 | 32 4 | 32.4 | 32 2 | 32.4 | 32.5 | 31.5 | 32.0 | 31.6 | 31.5 | 31.9 | 32.3 | 32.3 | 31.9 | 32.4 |
| 3 | Max.... | 32.3 | 32.5 | 32.4 | 32.3 | 32.5 | 32.6 | 31.4 | 32.1 | 31.7 | 31.1 | 31.4 | 32.4 | 32.4 | 32.0 | 32.5 |
| | Min.... | 31.8 | 32.3 | 32.4 | 32.2 | 32.4 | 32.4 | 31.2 | 32.0 | 31.7 | 31.0 | 31.4 | 32.2 | 32.3 | 31.9 | 32.4 |
| 4 | Max.... | 31.3 | 31.9 | 32.3 | 32.3 | 32.5 | 32.6 | 31.1 | 32.0 | 31.8 | 30.9 | 31.3 | 32.1 | 32.4 | 32.0 | 32.5 |
| | Min.... | 30.9 | 31.6 | 32.1 | 32.1 | 32 4 | 32.4 | 31.0 | 31 6 | 31.6 | 30.7 | 31.1 | 31.9 | 32.2 | 31.7 | 32.4 |
| 5 | Max.... | 32.1 | 32.3 | 32.4 | 32.2 | 32.4 | 32.4 | 31.4 | 32.0 | 31.6 | 32.1 | 31.9 | 32.1 | 32.3 | 31.9 | 32.4 |
| | Min.... | 31.9 | 32.3 | 32.3 | 32.0 | 32.3 | 32.4 | 31.1 | 31.7 | 31.5 | 31.4 | 31.4 | 32.0 | 32.1 | 31.8 | 32.3 |
| 6 | Max.... | 32.3 | 32.4 | 32.4 | 32.2 | 32.5 | 32.5 | 31.7 | 32.1 | 31.8 | 32.3 | 32.2 | 32.3 | 32.3 | 31.9 | 32.5 |
| | Min.... | 32.2 | 32.3 | 32.4 | 32.1 | 32.3 | 32.4 | 31.6 | 32.0 | 31.6 | 32.3 | 32.1 | 32.2 | 32.3 | 31.9 | 32.5 |
| 8 | Max.... | 32.4 | 32.5 | 32.5 | 32.3 | 32.5 | 32.8 | 31.6 | 32.2 | 31.9 | 32.3 | 32.3 | 32.4 | 32.4 | 32.0 | 32.6 |
| | Min.... | 32.2 | 32.4 | 32.5 | 32.2 | 32.4 | 32.6 | 31.5 | 32.1 | 31.7 | 32.1 | 32.1 | 32.4 | 32.2 | 31.9 | 32.4 |
| 9 | Max.... | 32.0 | 32.4 | 32.6 | 32.2 | 32.4 | 32.8 | 31.3 | 32.1 | 31.9 | 31.9 | 32.1 | 32.4 | 32.4 | 32.0 | 32.6 |
| | Min.... | 31.7 | 32.3 | 32.4 | 32.1 | 32.4 | 32.6 | 31.0 | 32.0 | 31.7 | 31.6 | 32.0 | 32.3 | 32.2 | 31.9 | 32.4 |
| 10 | Max.... | 31.6 | 32.1 | 32.6 | 32.3 | 32.6 | 33.0 | 30.9 | 32.0 | 32.1 | 31.4 | 32.1 | 32.6 | 32.4 | 32.1 | 32.6 |
| | Min.... | 31.0 | 31.9 | 32.3 | 32.1 | 32.3 | 32.7 | 30.5 | 31.6 | 31.6 | 30.9 | 31.5 | 32.2 | 32.2 | 31.9 | 32.3 |
| 11 | Max.... | 32.1 | 32.3 | 32.3 | 32.0 | 32.4 | 32.7 | 31.3 | 31.8 | 31.5 | 32.1 | 32.0 | 32.3 | 32.2 | 31.8 | 32.4 |
| | Min.... | 31.9 | 32.2 | 32.3 | 32.0 | 32.3 | 32.6 | 31.0 | 31.6 | 31.5 | 31.6 | 31.9 | 32.2 | 32.1 | 31.7 | 32.3 |
| 12 | Max.... | 32.1 | 32.3 | 32.4 | 32.1 | 32.4 | 32.8 | 31.5 | 32.0 | 31.6 | 32.2 | 32.1 | 32.3 | 32.3 | 31.9 | 32.4 |
| | Min.... | 32.1 | 32.3 | 32.3 | 32.0 | 32.3 | 32.6 | 31.4 | 31.9 | 31.5 | 32.2 | 32.1 | 32.3 | 32.2 | 31.8 | 32.3 |
| 13 | Max.... | 32.2 | 32.4 | 32.4 | 32.1 | 32.5 | 32.8 | 31.6 | 32.1 | 31.8 | 32.3 | 32.2 | 32.4 | 32.3 | 31.9 | 32.5 |
| | Min.... | 32.1 | 32.4 | 32.4 | 32.0 | 32.4 | 32.7 | 31.6 | 32 0 | 31 6 | 32.3 | 32.2 | 32.3 | 32.2 | 31.7 | 32.4 |
| 15 | Max.... | 32.2 | 32.4 | 32.6 | 32.2 | 32.5 | 32.9 | 31.8 | 32.1 | 31.8 | 32.4 | 32.4 | 32.4 | 32.3 | 31.9 | 32.4 |
| | Min.... | 32.2 | 32.3 | 32.6 | 32.1 | 32 5 | 32.8 | 31.8 | 32.1 | 31.7 | 32.4 | 32.3 | 32.4 | 32.3 | 31.9 | 32.4 |
| 16 | Max.... | 31.9 | 32.4 | 32.7 | 32.0 | 32.5 | 32.9 | 31.2 | 32.2 | 31.9 | 31.8 | 32.2 | 32.6 | 32.3 | 31.9 | 32.5 |
| | Min.... | 31.2 | 32.3 | 32.6 | 31.5 | 32.4 | 32.8 | 30.8 | 32.0 | 31.8 | 31.4 | 32.2 | 32.5 | 31.8 | 31.9 | 32.4 |
| 17 | Max.... | 32.1 | 32.3 | 32.2 | 32.1 | 32.3 | 32.5 | 31.1 | 31.4 | 32.0 | 32.1 | 31.8 | 32.5 | 31.8 | 31.4 | 32.5 |
| | Min.... | 27.0 | 29.4 | 32.1 | 25.6 | 29.0 | 32.3 | 27.3 | 31.0 | 31.5 | 28.5 | 31.1 | 32.2 | 28.2 | 31.3 | 32.3 |
| 18 | Max.... | 32.1 | 32.3 | 32.4 | 32.0 | 32.2 | 32.6 | 31.4 | 31.4 | 31.8 | 32.1 | 31.9 | 32.4 | 31.8 | 31.4 | 32.5 |
| | Min.... | 28.0 | 31.2 | 32.3 | 28.1 | 31.4 | 32.4 | 27.4 | 30.8 | 31.3 | 29.3 | 31.4 | 32.2 | 28.0 | 30.9 | 32.3 |
| 19 | Max.... | 32.0 | 32.0 | 32.4 | 31.9 | 32.1 | 32.7 | 30.5 | 31.4 | 31.8 | 31.1 | 31.4 | 32.4 | 31.0 | 30.9 | 32.4 |
| | Min.... | 28.0 | 31.2 | 32.2 | 28.1 | 31.5 | 32.4 | 28.4 | 31.0 | 31.3 | 29.5 | 31.3 | 32.1 | 27.8 | 30.4 | 32.3 |
| 20 | Max.... | 33.3 | 32.9 | 32.4 | 34.3 | 34.4 | 34.1 | 31.7 | 31.9 | 31.7 | 32.3 | 32.1 | 32.4 | 31.9 | 31.6 | 32.4 |
| | Min.... | 30.5 | 32.3 | 32.3 | 30.5 | 32.3 | 32.5 | 30.8 | 31.6 | 31.4 | 31.1 | 31.8 | 32.2 | 30.5 | 31.3 | 32.2 |
| 22 | Max.... | 41.5 | 41.0 | 39.9 | 41.3 | 41.1 | 40.3 | 35.6 | 32.3 | 31.7 | 36.6 | 32.8 | 32.4 | 32.1 | 31.6 | 32.3 |
| | Min.... | 37.4 | 37.0 | 36.4 | 37.4 | 37.1 | 36.7 | 32.9 | 32.0 | 31.6 | 33.9 | 32.3 | 32.3 | 32.1 | 31.5 | 32.2 |
| 24 | Max.... | 36.3 | 37.4 | 38.0 | 36.4 | 37.2 | 38.0 | 34.5 | 34.9 | 34.4 | 37.2 | 37.9 | 38.5 | 32.5 | 31.9 | 32.4 |
| | Min.... | 34.0 | 35.5 | 36.4 | 34.1 | 35.2 | 36.4 | 33.4 | 34.5 | 34.1 | 35.3 | 36.2 | 37.0 | 32.3 | 31.7 | 32.3 |
| 25 | Max.... | 32.9 | 33.7 | 34.3 | 33.1 | 33.7 | 34.5 | 32.6 | 33.5 | 33.4 | 33.7 | 34.3 | 35.1 | 32.3 | 31.9 | 32.4 |
| | Min.... | 32.7 | 33.5 | 34.0 | 32.7 | 33.5 | 34.1 | 32.6 | 33.4 | 33.4 | 33.5 | 34.0 | 34.5 | 32.3 | 31.8 | 32.4 |
| 26 | Max.... | 32.2 | 33.0 | 33.4 | 32.1 | 32.3 | 33.4 | 32.4 | 33.4 | 33.4 | 32.8 | 33.4 | 34.0 | 32.3 | 32.0 | 32.5 |
| | Min.... | 31.2 | 32.7 | 33.2 | 28.9 | 32.2 | 32.8 | 32.3 | 33.2 | 33.0 | 32.6 | 33.1 | 33.5 | 32.2 | 31.8 | 32.3 |
| 27 | Max.... | 32.1 | 32.2 | 32.8 | 32.0 | 32.2 | 32.2 | 32.3 | 33.1 | 33.0 | 32.2 | 33.0 | 33.4 | 32.4 | 32.1 | 32.5 |
| | Min.... | 28.6 | 31 5 | 32.4 | 22.1 | 25.8 | 30.7 | 32.1 | 32 8 | 32 6 | 31.1 | 32 5 | 33.0 | 32.1 | 31.7 | 32.3 |
| Ave. | Max.. | 32.76 | 33.01 | 33.13 | 32.86 | 33.13 | 33.40 | 31.82 | 32.26 | 32.08 | 32.49 | 32.48 | 32.87 | 32.20 | 31.83 | 32.47 |
| | Min.. | 31.43 | 32.41 | 32.80 | 31.14 | 32.23 | 32.88 | 31.06 | 32.02 | 31.86 | 31.66 | 32.16 | 32.67 | 31.56 | 31.65 | 32.35 |
| | Range | 1.33 | 0.60 | 0.33 | 1.72 | 0.90 | 0.52 | 0.76 | 0.24 | 0.22 | 0.83 | 0.32 | 0.25 | 0.64 | 0.18 | 0.12 |

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TABLE 66.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, MARCH, 1915.

| Date— Maximum, minimum. | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 | Max. | 32.1 | 32.3 | 32.0 | 32.1 | 32.3 | 32.2 | 31.6 | 32.6 | 32.5 | 31.9 | 31.4 | 32.3 | 31.8 | 32.1 | 32.5 |
| | Min. | 24.0 | 25.8 | 29.4 | 23.0 | 26.4 | 29.5 | 29.3 | 32.3 | 32.1 | 25.9 | 30.4 | 31.9 | 28 9 | 31.5 | 32 3 |
| 2 | Max. | 32.1 | 32.3 | 32.2 | 32.1 | 32.3 | 32.4 | 31.8 | 32.4 | 32.3 | 32.1 | 31.7 | 32.2 | 32.0 | 31.7 | 32.4 |
| | Min. | 30.7 | 31.8 | 32.2 | 31.2 | 32.2 | 32.3 | 31.2 | 32.3 | 32.2 | 30.7 | 31.5 | 32.1 | 31.7 | 31 6 | 32.3 |
| 3 | Max. | 32.0 | 32.4 | 31.9 | 32.2 | 32.4 | 32.3 | 31.7 | 32.4 | 32.4 | 31.8 | 31.1 | 32.1 | 31.4 | 31.1 | 32.5 |
| | Min. | 21.6 | 26.0 | 29.0 | 23.4 | 27.4 | 31.2 | 25.1 | 31.9 | 31.7 | 25 4 | 29.9 | 31.4 | 26 1 | 30.0 | 32.3 |
| 4 | Max. | 32.0 | 32.3 | 32.0 | 32.0 | 32.3 | 32.3 | 31.5 | 32.1 | 32.2 | 31.5 | 31.1 | 31.6 | 31.4 | 31.1 | 32.4 |
| | Min. | 25.1 | 27.9 | 29.7 | 25.9 | 28.6 | 31.4 | 27.0 | 31.6 | 31.7 | 27.1 | 29.9 | 31.2 | 27.8 | 30.1 | 32 2 |
| 5 | Max. | 31.2 | 31.7 | 31.8 | 31.4 | 32.0 | 32.4 | 30.7 | 31.6 | 31.8 | 31.1 | 31.2 | 31.7 | 31.3 | 31.2 | 32.3 |
| | Min. | 29.3 | 30.4 | 31.0 | 30.6 | 31.9 | 32.3 | 28.9 | 31.5 | 31.4 | 30.1 | 31.0 | 31.5 | 30 0 | 30.9 | 32.2 |
| 6 | Max. | 31.8 | 32.1 | 32.1 | 31.9 | 32.2 | 32.4 | 31.1 | 31.8 | 31.6 | 31.5 | 31.6 | 31.9 | 31.7 | 31.5 | 32.2 |
| | Min. | 31.5 | 32.0 | 32.0 | 31.6 | 32.1 | 32.3 | 31.0 | 31.8 | 31.6 | 31.4 | 31.5 | 31.8 | 31.6 | 31.4 | 32.1 |
| 8 | Max. | 32.3 | 32.4 | 32.4 | 32.1 | 32.4 | 32.5 | 31.6 | 32.2 | 32.0 | 31.9 | 32.1 | 32.2 | 32.0 | 32.7 | 32.3 |
| | Min. | 31.9 | 32.1 | 32.2 | 31.8 | 32.1 | 32.2 | 31.3 | 31.9 | 31.6 | 31.5 | 31.7 | 32.0 | 31.6 | 31 4 | 32.1 |
| 9 | Max. | 32.0 | 32.0 | 32.4 | 31.9 | 32.1 | 32.5 | 31.8 | 32.2 | 32.0 | 32.3 | 32.0 | 32.3 | 32.0 | 31.7 | 32.3 |
| | Min. | 31.0 | 31.7 | 32.1 | 29.4 | 31.3 | 32.2 | 31 1 | 32.0 | 31.5 | 31.2 | 31.5 | 31.9 | 31.4 | 31.3 | 32 1 |
| 10 | Max. | 32.3 | 32.4 | 32.3 | 32.0 | 32.4 | 32.4 | 32.0 | 32.3 | 31.9 | 32.4 | 32.0 | 32.2 | 32.3 | 31.7 | 32.3 |
| | Min. | 31.8 | 32.3 | 32.2 | 31.6 | 32.1 | 32.3 | 31.7 | 32.1 | 31.6 | 32.3 | 32.1 | 32.1 | 32.1 | 31.5 | 32 0 |
| 11 | Max. | 32.2 | 32.5 | 32.3 | 32.5 | 33.3 | 33.4 | 32.0 | 32.2 | 31.9 | 32.5 | 32.3 | 32.3 | 32.3 | 31.8 | 32.2 |
| | Min. | 32.1 | 32.3 | 32.3 | 32.1 | 32.3 | 32.4 | 31.8 | 32.1 | 31.7 | 32.3 | 32.2 | 32.1 | 32.1 | 31.7 | 32.1 |
| 12 | Max. | 37.6 | 38.5 | 37.6 | 38.4 | 39.4 | 38.8 | 32.4 | 32.3 | 32.0 | 33.9 | 32.4 | 32.3 | 32.3 | 31.9 | 32.3 |
| | Min. | 29.5 | 32.3 | 32 3 | 29.5 | 32.2 | 32.4 | 30.9 | 32.0 | 31.7 | 32.1 | 32.2 | 32.1 | 32.0 | 31.5 | 32.0 |
| 13 | Max. | 43.1 | 43.2 | 41.8 | 42.7 | 42.9 | 41.7 | 39.5 | 37.3 | 34.3 | 38.5 | 35.2 | 32.6 | 32.3 | 31.9 | 32.3 |
| | Min. | 31.9 | 32.8 | 33.1 | 31.0 | 32.5 | 33.2 | 31.8 | 32.1 | 31 8 | 32.3 | 32.2 | 32.2 | 32.0 | 31.5 | 32.0 |
| 15 | Max. | 41.9 | 39.4 | 38.3 | 41.4 | 39.4 | 38.5 | 39.7 | 38.2 | 37.0 | 39.6 | 38.1 | 37.5 | 33.4 | 31.8 | 32.2 |
| | Min. | 34.9 | 35.4 | 35.7 | 34.6 | 35.2 | 35.8 | 34 6 | 35.6 | 35.4 | 34.9 | 35.4 | 35.8 | 32.2 | 31.6 | 32.1 |
| 16 | Max. | 40.4 | 38.3 | 38.8 | 39.4 | 39.1 | 39.5 | 37.5 | 38.8 | 37.1 | 38.0 | 38.6 | 37.8 | 32.4 | 31.8 | 32.3 |
| | Min. | 31.4 | 33.2 | 33.9 | 32.0 | 33.1 | 34.0 | 32.5 | 33.8 | 33.6 | 33.1 | 34.0 | 34.1 | 32.3 | 31.6 | 32.1 |
| 17 | Max. | 36.6 | 38.0 | 37.8 | 38.8 | 39.7 | 39.4 | 36.1 | 36.5 | 34.8 | 36.3 | 36.1 | 35.3 | 32.3 | 32.0 | 32.3 |
| | Min. | 29.0 | 32.3 | 33.0 | 30.0 | 32.4 | 33.2 | 30.6 | 33.4 | 33.4 | 31.9 | 33.0 | 33.6 | 32.1 | 31.6 | 32.1 |
| 18 | Max. | 43.1 | 41.9 | 41.2 | 43.1 | 43.5 | 42.7 | 41.3 | 40.5 | 37.6 | 41.2 | 39.9 | 38.2 | 32.3 | 31.9 | 32.3 |
| | Min. | 30.5 | 32.6 | 34.0 | 30.8 | 32.6 | 33.6 | 31.9 | 33.0 | 33.0 | 32.5 | 32.9 | 33.4 | 32.1 | 31.5 | 32.1 |
| 19 | Max. | 44.5 | 42.2 | 41.5 | 43.4 | 43.3 | 42.6 | 41.0 | 41.1 | 38.7 | 41.8 | 40.8 | 39.2 | 32.3 | 31.9 | 32.3 |
| | Min. | 32 1 | 33.4 | 34.4 | 32 2 | 33.4 | 34.5 | 32.9 | 34.5 | 34.4 | 33.4 | 34.3 | 34.7 | 32.1 | 31 6 | 32 1 |
| 20 | Max. | 47.3 | 41.6 | 41.2 | 45.4 | 41.9 | 41.8 | 43.1 | 40.0 | 38.5 | 41.5 | 40.5 | 39.5 | 32.7 | 31.9 | 32.3 |
| | Min. | 32.3 | 33.7 | 34.8 | 32.4 | 33.7 | 34.9 | 33.2 | 34 8 | 35.1 | 33.6 | 34.8 | 35.6 | 32.3 | 31 6 | 32 1 |
| 22 | Max. | 38.1 | 38.2 | 37.8 | 38.2 | 38.3 | 38.0 | 37.4 | 37.0 | 35.5 | 38.0 | 37.3 | 36.6 | 32.3 | 31.9 | 32.3 |
| | Min. | 32.8 | 33.6 | 34.1 | 33.0 | 33.6 | 34.3 | 33.4 | 33 5 | 33.4 | 33 4 | 34.0 | 34 4 | 32.2 | 31 7 | 32 2 |
| 23 | Max. | 46.0 | 44.1 | 43.2 | 45.1 | 44.5 | 43.9 | 41.0 | 40.8 | 38.4 | 42.6 | 41.4 | 39.6 | 32.8 | 31.9 | 32.3 |
| | Min. | 32.1 | 33.2 | 34.0 | 32.1 | 33 0 | 33.9 | 32.4 | 33.9 | 34.0 | 33.2 | 34.0 | 34.6 | 32 0 | 31.5 | 32 2 |
| 24 | Max. | 44.2 | 43.7 | 42.4 | 44.3 | 43.8 | 42.5 | 42.1 | 40.6 | 38.0 | 42.5 | 40.8 | 39.2 | 34.0 | 31.9 | 32.3 |
| | Min. | 32.5 | 33 9 | 34.8 | 32.7 | 33 8 | 34.9 | 32.6 | 34.4 | 34.6 | 33.8 | 34.7 | 35.5 | 32.2 | 31.6 | 32.2 |
| 25 | Max. | 41.4 | 41.1 | 41.2 | 41.4 | 41.4 | 41.7 | 40.2 | 40.2 | 39.0 | 40.4 | 40.4 | 39.8 | 34.4 | 31.8 | 32.2 |
| | Min. | 38.9 | 39.2 | 39.1 | 38.8 | 39.1 | 39.5 | 38 1 | 38.3 | 37.6 | 38.9 | 38.7 | 38.6 | 33.1 | 31.5 | 32.2 |
| 26 | Max. | 35.7 | 37.6 | 38.0 | 36.2 | 37.6 | 38.3 | 33.6 | 34.8 | 34.9 | 35.9 | 36.4 | 36.2 | 32.3 | 32.0 | 32.3 |
| | Min. | 30.3 | 32.9 | 33.7 | 30.8 | 32 8 | 33.9 | 30 9 | 33.9 | 34.1 | 32.8 | 33.7 | 34.8 | 32.2 | 31 8 | 32 3 |
| 27 | Max. | 39.3 | 40.2 | 39.4 | 39.9 | 40.4 | 39.9 | 36.5 | 36.1 | 34.5 | 37.6 | 36.9 | 35.8 | 32.0 | 32.0 | 32.3 |
| | Min. | 29.7 | 32.0 | 32.9 | 29.4 | 31.7 | 33.0 | 30.5 | 32.6 | 33.0 | 31.8 | 32.9 | 33.6 | 31.5 | 31 6 | 32.2 |
| 29 | Max. | 31.5 | 32.3 | 32.6 | 31.0 | 31.8 | 32.8 | 31.4 | 32.6 | 33.0 | 32.2 | 32.9 | 33.7 | 31.8 | 32.0 | 32.4 |
| | Min. | 28 4 | 30 9 | 32 4 | 27.9 | 30.4 | 32 5 | 29.8 | 32.3 | 32.5 | 31.0 | 32.6 | 33.4 | 30.4 | 31.9 | 32 3 |
| 30 | Max. | 33.5 | 33.3 | 32.3 | 33.4 | 33.6 | 32.5 | 32.0 | 31.8 | 32.3 | 32.6 | 32.1 | 32.8 | 31.9 | 32.0 | 32.4 |
| | Min. | 27 3 | 29 9 | 31.7 | 25.8 | 28.3 | 31.5 | 27.9 | 31.5 | 31 9 | 28.4 | 31.8 | 32.3 | 31.4 | 31.6 | 32.2 |
| 31 | Max. | 34.9 | 33.2 | 33.3 | 34.4 | 34.3 | 34.5 | 31.9 | 32.2 | 32.1 | 32.4 | 32.4 | 32.6 | 32.1 | 31.9 | 32.3 |
| | Min. | 30.4 | 32.1 | 32 4 | 30 0 | 31.8 | 32.6 | 31.2 | 32.1 | 32.0 | 32.0 | 32.2 | 32.6 | 31.4 | 31.8 | 32.3 |
| Ave. | Max. | 37.01 | 36.64 | 36.28 | 36.92 | 36.99 | 36.81 | 35.28 | 35.28 | 34.38 | 35.70 | 35.14 | 34.80 | 32.29 | 31.82 | 32.32 |
| | Min. | 30.48 | 32.08 | 32.80 | 30.50 | 32.07 | 33.18 | 31.24 | 33.01 | 32.91 | 31.74 | 32.71 | 33.31 | 31.36 | 31.43 | 32.16 |
| | Range | 6.53 | 4.58 | 3.39 | 6.42 | 4.92 | 3.63 | 4.04 | 2.27 | 1.47 | 3.96 | 2.43 | 1.49 | 0.93 | 0.39 | 0.16 |

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TABLE 67.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, APRIL, 1915.

| Date—Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" |
| 1 Max.... | 41.2 | 39.3 | 38.5 | 42.2 | 40.2 | 39.7 | 34.4 | 33.3 | 32.3 | 36.3 | 34.9 | 34.0 | 32.2 | 31.7 | 32.3 |
| 1 Min.... | 32.1 | 32.6 | 33.0 | 32.2 | 32.6 | 33.3 | 31.8 | 32.1 | 32.1 | 32.4 | 32.3 | 32.6 | 32.1 | 31.6 | 32.3 |
| 2 Max.... | 43.9 | 41.4 | 40.4 | 43.9 | 41.9 | 41.1 | 40.8 | 39.4 | 37.0 | 40.4 | 39.1 | 37.7 | 32.3 | 31.8 | 32.3 |
| 2 Min.... | 32.6 | 33.4 | 34.0 | 32.6 | 33.4 | 34.3 | 32.3 | 33.1 | 32.9 | 33.0 | 33.4 | 33.6 | 32.1 | 31.6 | 32.3 |
| 3 Max.... | 45.3 | 45.2 | 43.4 | 45.1 | 45.0 | 43.7 | 44.2 | 42.3 | 38.7 | 43.4 | 41.5 | 39.4 | 32.3 | 31.9 | 32.4 |
| 3 Min.... | 31.9 | 33.1 | 34.0 | 31.9 | 33.0 | 34.0 | 32.3 | 34.0 | 33.7 | 33.2 | 34.0 | 34.4 | 32.1 | 31.6 | 32.3 |
| 5 Max.... | 46.0 | 45.0 | 43.5 | 46.6 | 45.7 | 44.3 | 44.9 | 42.8 | 40.3 | 44.5 | 42.4 | 41.0 | 33.5 | 31.7 | 32.3 |
| 5 Min.... | 38.9 | 38.8 | 38.7 | 38.7 | 38.7 | 38.7 | 38.4 | 38.5 | 37.7 | 38.8 | 38.6 | 38.4 | 32.2 | 31.6 | 32.3 |
| 6 Max.... | 57.4 | 54.2 | 51.9 | 57.9 | 55.9 | 53.6 | 54.6 | 51.3 | 46.0 | 53.7 | 50.5 | 47.0 | 39.5 | 31.8 | 32.4 |
| 6 Min.... | 39.5 | 38.4 | 38.3 | 38.8 | 38.2 | 38.1 | 38.2 | 38.3 | 37.9 | 38.4 | 38.3 | 38.6 | 32.3 | 31.6 | 32.3 |
| 7 Max.... | 60.1 | 58.6 | 55.8 | 60.0 | 59.2 | 57.0 | 58.2 | 54.6 | 49.3 | 56.9 | 53.5 | 49.9 | 41.5 | 31.8 | 32.4 |
| 7 Min.... | 41.7 | 41.6 | 42.1 | 41.0 | 41.1 | 41.8 | 41.4 | 42.1 | 41.8 | 42.0 | 42.2 | 42.5 | 33.4 | 31.6 | 32.3 |
| 8 Max.... | 60.8 | 58.3 | 55.9 | 59.4 | 58.3 | 56.2 | 57.5 | 54.9 | 50.0 | 56.3 | 53.2 | 50.2 | 41.4 | 31.8 | 32.5 |
| 8 Min.... | 41.4 | 41.0 | 41.7 | 39.8 | 39.6 | 40.6 | 40.5 | 41.8 | 42.5 | 40.7 | 41.5 | 42.9 | 32.3 | 31.6 | 32.3 |
| 9 Max.... | 55.5 | 53.8 | 51.9 | 55.8 | 54.5 | 52.7 | 54.0 | 51.4 | 48.1 | 53.0 | 50.2 | 48.7 | 44.6 | 33.4 | 32.9 |
| 9 Min.... | 47 0 | 46.1 | 45.9 | 46.2 | 45.7 | 45.7 | 46.0 | 45.9 | 45.3 | 45.4 | 45.6 | 45.6 | 34.7 | 32.0 | 32.7 |
| 10 Max.... | 54.0 | 52.6 | 51.0 | 54.4 | 53.1 | 51.5 | 53.1 | 50.7 | 48.7 | 52.5 | 50.2 | 49.6 | 45.2 | 39.4 | 37.5 |
| 10 Min.... | 50.7 | 50.2 | 49.4 | 50.9 | 50.2 | 49.7 | 50.2 | 49.3 | 47.7 | 49.9 | 48.9 | 48.6 | 42.4 | 34.9 | 33.9 |
| 12 Max.... | 40.3 | 40.7 | 41.2 | 40.1 | 40.5 | 41.0 | 40.5 | 41.4 | 40.9 | 41.1 | 41.5 | 41.8 | 40.5 | 40.2 | 41.4 |
| 12 Min.... | 36.4 | 37.5 | 39.0 | 35.6 | 36.8 | 38.5 | 36.9 | 39.4 | 40.4 | 38.0 | 39.6 | 41.2 | 37.5 | 39.5 | 40.8 |
| 13 Max.... | 57.1 | 53.3 | 51.4 | 57.4 | 56.1 | 53.8 | 53.7 | 51.5 | 47.0 | 52.9 | 50.2 | 47.3 | 53.1 | 46.7 | 42.3 |
| 13 Min.... | 33.2 | 34.9 | 36.5 | 32.5 | 34.0 | 35.7 | 34.3 | 36.8 | 37.9 | 34.8 | 36.6 | 38.1 | 35.6 | 37.6 | 39.1 |
| 14 Max.... | 62.9 | 58.6 | 56.4 | 63.3 | 59.9 | 58.1 | 56.8 | 54.6 | 49.8 | 57.3 | 54.8 | 51.6 | 55.1 | 49.5 | 44.7 |
| 14 Min.... | 39.2 | 38.2 | 39.1 | 38.1 | 37.7 | 38.6 | 57.0 | 39.0 | 40.2 | 37.8 | 38.6 | 40.3 | 37.6 | 40.2 | 41.5 |
| 15 Max.... | 66.7 | 61.5 | 57.3 | 69.1 | 62.9 | 58.7 | 63.5 | 56.5 | 51.2 | 61.7 | 55.6 | 52.6 | 55.4 | 49.5 | 45.5 |
| 15 Min.... | 37.1 | 39.5 | 41.7 | 36.2 | 38.1 | 40.9 | 37.6 | 41.3 | 42.7 | 37.9 | 40.3 | 42.9 | 39.3 | 42.3 | 43.3 |
| 16 Max .... | 54.1 | 52.0 | 50.5 | 55.2 | 53.3 | 51.3 | 52.9 | 50.2 | 48.3 | 52.4 | 49.7 | 49.1 | 51.1 | 48.0 | 47.0 |
| 16 Min.... | 46 8 | 47.5 | 48.0 | 46 5 | 47.4 | 47.9 | 46.9 | 47.7 | 47.0 | 47.2 | 47 1 | 47.7 | 46.5 | 46.3 | 46.4 |
| 17 Max.... | 70.3 | 64.9 | 59.9 | 71.0 | 66.6 | 62.2 | 66.6 | 59.8 | 52.4 | 63.5 | 58.2 | 53.4 | 58.0 | 50.6 | 46.0 |
| 17 Min.... | 34.7 | 37.5 | 39.9 | 33.6 | 35.9 | 38 6 | 36.4 | 40 4 | 42.1 | 36.4 | 39.2 | 41.7 | 58.7 | 42.1 | 43.9 |
| 19 Max.... | 73.8 | 68.6 | 64.4 | 73.3 | 69.6 | 66.0 | 70.4 | 64.7 | 57.9 | 68.2 | 63.6 | 59.1 | 61.8 | 55.0 | 50.5 |
| 19 Min.... | 49.9 | 50.3 | 50.7 | 49.9 | 50.2 | 50.8 | 49.8 | 50.5 | 49.6 | 49.5 | 49.7 | 50.2 | 49.6 | 48.0 | 48.3 |
| 20 Max.... | 74.0 | 68.1 | 64.9 | 72.7 | 68.6 | 65.8 | 70.9 | 65.6 | 59.7 | 68.1 | 64.0 | 60.6 | 62.3 | 57.0 | 52.9 |
| 20 Min.... | 50.6 | 51.8 | 52.9 | 50.6 | 51.5 | 52.8 | 51.4 | 53 0 | 52.8 | 51.1 | 52 0 | 53.0 | 49.6 | 50.5 | 51.0 |
| 21 Max.... | 65.9 | 62.1 | 58.7 | 64.7 | 62.0 | 59.0 | 64.1 | 59.1 | 55.8 | 62.0 | 57.5 | 56.1 | 56.4 | 53.1 | 51.5 |
| 21 Min.... | 45.9 | 48.0 | 50.0 | 46.1 | 47.4 | 49 7 | 47.3 | 50 4 | 51.6 | 46 9 | 48.5 | 50.8 | 46.0 | 49.4 | 50.5 |
| 22 Max.... | 68.0 | 65.1 | 61.6 | 69.0 | 66.7 | 63.3 | 67.2 | 62.1 | 56.6 | 65.2 | 61.4 | 57.7 | 63.3 | 56.5 | 52.5 |
| 22 Min.... | 50.2 | 50.7 | 51 3 | 50 0 | 50.3 | 51.0 | 50.5 | 51 5 | 51.2 | 49.9 | 50.4 | 51.1 | 48.9 | 49.6 | 50 7 |
| 23 Max.... | 83.7 | 76.6 | 71.8 | 84.0 | 78.2 | 74.1 | 81.2 | 73.0 | 65.1 | 77.6 | 71.0 | 66.2 | 73.7 | 65.5 | 58.4 |
| 23 Min.... | 54.6 | 54.5 | 54.7 | 54.4 | 54.5 | 54.8 | 54.9 | 55.2 | 54.1 | 54.6 | 54.5 | 54.6 | 54 2 | 54.0 | 53.9 |
| 24 Max.... | 86.1 | 80.6 | 75.7 | 84.9 | 81.2 | 77.2 | 83.7 | 76.9 | 68.7 | 80.3 | 75.2 | 69.8 | 75.7 | 68.4 | 62.0 |
| 24 Min.... | 59.5 | 60.4 | 60.8 | 59.9 | 60.5 | 61.2 | 60.8 | 61.5 | 60.2 | 60.0 | 59.8 | 60.6 | 59.8 | 59.9 | 59.1 |
| 26 Max.... | 87.8 | 80.9 | 77.0 | 85.7 | 80.7 | 77.5 | 85.8 | 78.3 | 71.8 | 82.2 | 76.4 | 72.6 | 77.6 | 70.8 | 65.8 |
| 26 Min.... | 61.1 | 62.5 | 63.5 | 61.1 | 61.8 | 63.1 | 62.0 | 64.1 | 63.9 | 61.5 | 61.7 | 63.7 | 60.8 | 62.5 | 63.4 |
| 27 Max.... | 84.1 | 78.2 | 75.5 | 81.7 | 77.7 | 75.5 | 82.3 | 76.8 | 71.1 | 79.6 | 74.8 | 71.8 | 74.2 | 69.7 | 65.7 |
| 27 Min.... | 61.7 | 63.1 | 64.3 | 61.8 | 62.6 | 64.0 | 63 3 | 65.0 | 64.8 | 62 0 | 62.0 | 64.4 | 61.4 | 63.1 | 63.8 |
| 28 Max.... | 80.5 | 78.0 | 75.0 | 81.3 | 77.3 | 75.1 | 82.1 | 76.7 | 71.0 | 79.3 | 74.5 | 71.6 | 75.1 | 70.0 | 66.0 |
| 28 Min.... | 60.5 | 62.2 | 63.5 | 61.0 | 61.9 | 63.4 | 62.3 | 64.4 | 64.4 | 61.1 | 62.6 | 64.0 | 60.5 | 62.8 | 64.1 |
| 29 Max.... | 74.5 | 71.8 | 68.1 | 74.6 | 71.4 | 68.2 | 75.1 | 69.3 | 66.5 | 71.8 | 66.9 | 66.2 | 68.4 | 64.8 | 64.1 |
| 29 Min.... | 56.3 | 59.4 | 61 9 | 57.2 | 59.1 | 61.8 | 58.6 | 62.5 | 63 6 | 57.1 | 60.1 | 62.6 | 57.0 | 61.7 | 62.7 |
| 30 Max.... | 55.5 | 55.7 | 57.8 | 55.8 | 55.7 | 57.7 | 56.8 | 57.1 | 59.5 | 54.8 | 56.0 | 58.2 | 55.5 | 57.5 | 61.0 |
| 30 Min.... | 52.7 | 54.5 | 56 0 | 53.2 | 54.3 | 55.8 | 54.7 | 58.3 | 57.0 | 53.2 | 54.6 | 55.9 | 53.7 | 56.3 | 58.5 |
| Ave. Max.. | 63.56 | 60.20 | 57.69 | 63.46 | 60.85 | 58.63 | 61.36 | 57.48 | 53.22 | 59.81 | 56.42 | 53.97 | 53.88 | 48.78 | 46.70 |
| Ave. Min.. | 45.63 | 46.45 | 47.34 | 45.38 | 46.02 | 47.11 | 45.99 | 47.55 | 47.51 | 45.88 | 46.62 | 47.99 | 44.63 | 44.38 | 45.15 |
| Ave. Range | 17.93 | 13.75 | 10.35 | 18.08 | 14.83 | 11.52 | 15.37 | 9.93 | 5.71 | 13.93 | 9.80 | 5.98 | 9.25 | 4.40 | 1.55 |

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TABLE 68.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, MAY, 1915.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 Max.... | 65.3 | 62.3 | 60.6 | 63.3 | 62.4 | 60.9 | 63.7 | 61.8 | 58.0 | 61.8 | 60.0 | 58.0 | 61.6 | 58.4 | 56.7 |
| 1 Min.... | 47.6 | 49.7 | 50.8 | 47.8 | 48.9 | 50.7 | 48.8 | 51.6 | 52.8 | 48.1 | 49.6 | 51.8 | 48.8 | 52.0 | 55.0 |
| 3 Max.... | 52.9 | 54.7 | 55.9 | 53.5 | 54.7 | 56.3 | 54.1 | 56.5 | 56.9 | 53.4 | 53.3 | 56.0 | 53.8 | 55.8 | 58.0 |
| 3 Min.... | 52.0 | 53.3 | 54.0 | 51.8 | 52.9 | 53.9 | 53.4 | 54.6 | 54.4 | 53.0 | 52.9 | 54.2 | 53.3 | 54.3 | 55.9 |
| 4 Max.... | 49.7 | 51.0 | 51.4 | 49.6 | 50.6 | 51.2 | 51.3 | 52.0 | 51.7 | 51.1 | 50.6 | 51.5 | 52.2 | 52.0 | 54.2 |
| 4 Min.... | 47.0 | 49.0 | 49.8 | 46.4 | 47.8 | 49.4 | 48.6 | 50.5 | 50.5 | 48.6 | 49.2 | 50.5 | 49.4 | 50.8 | 53.0 |
| 5 Max.... | 57.8 | 57.4 | 55.9 | 58.6 | 58.3 | 57.3 | 58.1 | 56.5 | 53.4 | 57.6 | 54.7 | 54.1 | 59.0 | 55.1 | 53.1 |
| 5 Min.... | 45.0 | 46.2 | 47.5 | 44.6 | 45.4 | 46.5 | 45.7 | 47.8 | 48.5 | 46.0 | 46.2 | 48.6 | 46.3 | 48.8 | 51.5 |
| 6 Max.... | 69.1 | 64.3 | 61.2 | 72.3 | 67.9 | 63.6 | 65.2 | 60.4 | 56.4 | 65.9 | 61.0 | 58.3 | 63.0 | 59.1 | 55.1 |
| 6 Min.... | 45.5 | 45.9 | 47.3 | 44.7 | 44.9 | 46.1 | 45.4 | 47.3 | 48.5 | 45.6 | 45.8 | 48.8 | 44.6 | 48.0 | 51.7 |
| 7 Max.... | 57.0 | 57.9 | 57.6 | 58.8 | 59.1 | 58.8 | 58.0 | 57.5 | 55.2 | 57.7 | 57.2 | 56.4 | 59.2 | 57.2 | 55.7 |
| 7 Min.... | 53.4 | 53.7 | 54.0 | 53.6 | 53.7 | 54.1 | 53.2 | 53.9 | 53.2 | 53.9 | 53.8 | 54.2 | 53.9 | 54.4 | 55.0 |
| 8 Max.... | 55.5 | 56.0 | 55.4 | 56.9 | 57.2 | 56.7 | 55.7 | 54.9 | 52.8 | 56.0 | 54.0 | 54.0 | 56.9 | 54.4 | 53.9 |
| 8 Min.... | 47.5 | 48.5 | 49.6 | 47.3 | 47.8 | 48.9 | 47.8 | 49.6 | 50.1 | 48.0 | 49.1 | 50.4 | 48.4 | 50.7 | 53.2 |
| 10 Max.... | 73.2 | 66.9 | 63.4 | 76.2 | 69.4 | 66.5 | 65.7 | 61.8 | 56.1 | 65.6 | 61.6 | 58.0 | 65.5 | 59.0 | 53.4 |
| 10 Min.... | 39.6 | 41.0 | 43.2 | 38.4 | 39.4 | 41.8 | 39.6 | 43.1 | 45.4 | 40.7 | 42.5 | 45.4 | 40.5 | 45.1 | 49.5 |
| 11 Max.... | 78.7 | 72.6 | 68.5 | 79.6 | 74.2 | 70.8 | 73.4 | 67.7 | 61.1 | 71.2 | 66.7 | 62.4 | 68.9 | 62.2 | 56.1 |
| 11 Min.... | 46.4 | 47.5 | 49.4 | 45.7 | 46.5 | 48.4 | 45.8 | 48.6 | 49.7 | 46.7 | 48.2 | 50.2 | 45.4 | 49.2 | 52.5 |
| 12 Max.... | 82.9 | 75.2 | 71.6 | 83.1 | 77.3 | 73.6 | 78.3 | 71.3 | 65.0 | 76.0 | 69.9 | 66.1 | 71.9 | 65.1 | 59.3 |
| 12 Min.... | 51.5 | 52.8 | 54.3 | 50.9 | 51.7 | 53.5 | 51.6 | 53.9 | 54.7 | 51.4 | 52.8 | 54.5 | 50.1 | 53.5 | 55.7 |
| 13 Max.... | 76.4 | 69.6 | 67.6 | 75.3 | 70.1 | 68.5 | 71.4 | 68.0 | 63.6 | 70.6 | 66.2 | 64.1 | 68.4 | 63.8 | 59.8 |
| 13 Min.... | 55.0 | 56.5 | 58.0 | 54.8 | 55.6 | 57.6 | 54.7 | 58.0 | 58.4 | 55.3 | 56.5 | 58.3 | 54 4 | 57.0 | 57.7 |
| 14 Max.... | 81.9 | 74.4 | 71.2 | 80.3 | 74.8 | 72.0 | 76.5 | 71.5 | 65.8 | 75.2 | 68.9 | 66.0 | 70.1 | 65.3 | 60.5 |
| 14 Min.... | 51.0 | 53.0 | 54.5 | 50.2 | 51.2 | 53.4 | 50.2 | 54.5 | 56.0 | 51.0 | 52.6 | 55.4 | 50.0 | 54.3 | 57.4 |
| 15 Max.... | 69.0 | 66.4 | 64.3 | 67.4 | 66.0 | 64.3 | 65,8 | 64.2 | 60.8 | 65.0 | 62.5 | 60.8 | 63.0 | 59.5 | 58.5 |
| 15 Min.... | 51.0 | 53.7 | 56.2 | 50.4 | 52.3 | 55.2 | 50.7 | 56.1 | 57.9 | 50.7 | 53.5 | 56.7 | 50.1 | 55.1 | 56.8 |
| 17 Max.... | 53.2 | 53.0 | 53.0 | 54.0 | 53.5 | 53.6 | 52.2 | 53.5 | 52.1 | 53.0 | 52.8 | 52.6 | 54.0 | 52.9 | 52.8 |
| 17 Min.... | 44.0 | 45.7 | 47.6 | 43.5 | 44.7 | 46.6 | 44.2 | 48.2 | 49.8 | 45.5 | 47.2 | 49.6 | 45.4 | 49.0 | 51.9 |
| 18 Max.... | 53.0 | 51.9 | 51.1 | 53.3 | 52.0 | 51.5 | 51.8 | 51.7 | 49.7 | 52.4 | 51.1 | 50.5 | 53.0 | 50.5 | 49.8 |
| 18 Min.... | 39.3 | 41.8 | 44.3 | 38.0 | 40.3 | 43.0 | 39.7 | 44.6 | 46.7 | 41.0 | 43.6 | 46.5 | 41.1 | 45.8 | 50.2 |
| 19 Max.... | 67.5 | 64.2 | 61.0 | 70.3 | 66.4 | 63.6 | 62.7 | 59.2 | 54.2 | 62.2 | 58.0 | 55.6 | 62.5 | 56.0 | 51.4 |
| 19 Min.... | 39.5 | 40.5 | 42.2 | 37.6 | 38.3 | 40.7 | 38.2 | 42.2 | 44.3 | 40.7 | 41.2 | 44.3 | 39.7 | 44.5 | 48.2 |
| 20 Max.... | 51.0 | 50.6 | 50.5 | 51.0 | 50.8 | 50.4 | 49.2 | 49.9 | 49.4 | 50.3 | 49.2 | 50.0 | 50.2 | 49.7 | 51.1 |
| 20 Min.... | 46.2 | 48.0 | 49.2 | 46.0 | 47.2 | 48.9 | 45.6 | 49.5 | 48.9 | 46.7 | 46.5 | 49.4 | 46.8 | 48.9 | 50.3 |
| 21 Max.... | 67.5 | 64.1 | 61.8 | 70.4 | 66.6 | 64.6 | 64.3 | 60.5 | 56.2 | 64.7 | 60.5 | 58.2 | 64.3 | 58.9 | 54.1 |
| 21 Min.... | 50.5 | 50.5 | 50.2 | 50.6 | 50.4 | 50.3 | 49.2 | 50.0 | 49.0 | 50.5 | 49.3 | 49.9 | 50.5 | 49.6 | 50.3 |
| 22 Max.... | 60.9 | 60.1 | 58.6 | 62.0 | 61.5 | 60.0 | 59.4 | 57.5 | 54.5 | 58.5 | 55.7 | 55.6 | 59.0 | 55.8 | 54.0 |
| 22 Min.... | 50.0 | 50.6 | 51.8 | 49.8 | 50.0 | 51.3 | 49.7 | 51.2 | 51.6 | 50.3 | 49.5 | 52.3 | 50.4 | 52.2 | 53.3 |
| 24 Max.... | 71.2 | 69.6 | 66.7 | 73.5 | 71.0 | 68.5 | 69.9 | 66.0 | 61.6 | 68.1 | 64.7 | 62.5 | 67.6 | 70.8 | 58.7 |
| 24 Min.... | 55.5 | 56.2 | 56.9 | 55.2 | 55.7 | 56.7 | 55.5 | 56.5 | 55.9 | 55.6 | 55.4 | 56.1 | 55.4 | 55.8 | 56.4 |
| 25 Max.... | 68.9 | 66.8 | 64.1 | 70.0 | 68.2 | 65.5 | 67.5 | 63.8 | 60.5 | 66.1 | 62.7 | 61.2 | 65.5 | 61.4 | 59.3 |
| 25 Min.... | 56.5 | 56.5 | 57.1 | 55.9 | 55.7 | 56.5 | 55.9 | 56.8 | 56.7 | 55.9 | 55.8 | 57.0 | 56.2 | 56.9 | 58.0 |
| 26 Max.... | 61.4 | 59.6 | 59.4 | 62.7 | 61.0 | 60.8 | 59.4 | 58.7 | 57.3 | 59.0 | 57.7 | 56.0 | 59.6 | 58.3 | 58.8 |
| 26 Min.... | 53.3 | 55.7 | 57.0 | 53.1 | 54.9 | 56.9 | 55.0 | 56.9 | 55.5 | 55.2 | 56.3 | 56.1 | 56.5 | 56.4 | 57.4 |
| 27 Max.... | 68.2 | 63.2 | 61.5 | 68.1 | 64.1 | 62.3 | 63.3 | 60.3 | 56.3 | 62.3 | 59.1 | 57.3 | 61.4 | 57.2 | 54.6 |
| 27 Min.... | 41.0 | 42.6 | 45.2 | 39.4 | 40.7 | 43.2 | 40.9 | 45.4 | 48.0 | 41.7 | 44.1 | 47.0 | 45.0 | 48.5 | 52.5 |
| 28 Max.... | 61.2 | 59.1 | 57.7 | 58.7 | 59.5 | 58.9 | 58.9 | 56.8 | 54.4 | 58.1 | 55.5 | 55.2 | 57.5 | 55.1 | 54.1 |
| 28 Min.... | 48.3 | 49.1 | 50.4 | 47.3 | 47.6 | 48.9 | 47.8 | 49.9 | 50.8 | 48.0 | 48.8 | 50.7 | 48.3 | 50.8 | 53.1 |
| 29 Max.... | 58.1 | 57.2 | 56.5 | 58.8 | 57.8 | 57.0 | 57.4 | 56.3 | 54.3 | 57.3 | 55.5 | 55.1 | 58.0 | 55.6 | 54.8 |
| 29 Min.... | 51.5 | 52.1 | 52.8 | 51.0 | 51.4 | 52.3 | 51.4 | 52.5 | 52.4 | 51.7 | 51.9 | 52.8 | 51.9 | 52.6 | 54.0 |
| 31 Max.... | 83.1 | 75.4 | 71.6 | 83.2 | 77.4 | 73.8 | 74.9 | 70.9 | 64.5 | 74.8 | 68.9 | 65.1 | 71.2 | 64.7 | 59.0 |
| 31 Min.... | 50.8 | 51.3 | 52.7 | 50.1 | 50.1 | 51.6 | 50.0 | 52.1 | 53.3 | 50.4 | 51.1 | 53.2 | 49.7 | 52.9 | 55.7 |
| Ave. Max.. | 65.18 | 62.45 | 61.09 | 65.80 | 63.54 | 61.96 | 62.63 | 60.36 | 57.00 | 62.09 | 59.15 | 57.79 | 61.44 | 58.22 | 55.65 |
| Ave. Min.. | 48.42 | 49.67 | 51.00 | 47.86 | 48.66 | 50.25 | 48.41 | 50.98 | 51.65 | 48.94 | 49.75 | 51.69 | 48.93 | 51.43 | 53.71 |
| Ave. Range | 16.76 | 12.78 | 10.09 | 17.94 | 14.88 | 11.71 | 14.22 | 9.38 | 5.35 | 13.15 | 9.40 | 6.10 | 12.51 | 6.78 | 1.94 |

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TABLE 69.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JUNE, 1915.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 | Max.... | 81.5 | 75.9 | 72.0 | 81.7 | 77.4 | 73.6 | 78.0 | 71.6 | 66.1 | 75.4 | 69.4 | 66.5 | 71.6 | 65.5 | 61.0 |
| | Min.... | 54.1 | 55.3 | 56.9 | 53.5 | 54.0 | 56.0 | 53.2 | 56.5 | 57.3 | 53.8 | 54.8 | 57.0 | 53.2 | 56.1 | 58.1 |
| 2 | Max.... | 63.4 | 63.3 | 63.0 | 63.4 | 63.4 | 63.2 | 63.2 | 63.0 | 61.3 | 62.6 | 61.5 | 61.4 | 63.0 | 60.9 | 60.8 |
| | Min.... | 59.9 | 61.0 | 61.8 | 59.8 | 60.5 | 61.5 | 60.0 | 61.5 | 60.8 | 59.2 | 59.5 | 60.9 | 59.1 | 60.0 | 60.3 |
| 3 | Max.... | 60.8 | 60.8 | 60.3 | 60.8 | 60.8 | 60.5 | 59.6 | 60.3 | 58.5 | 61.1 | 59.6 | 59.3 | 61.5 | 59.6 | 59.2 |
| | Min.... | 57.4 | 57.8 | 58.2 | 57.1 | 57.4 | 57.9 | 57.4 | 58.4 | 57.9 | 57.8 | 57.4 | 58.2 | 58.1 | 58.3 | 58.9 |
| 4 | Max.... | 83.7 | 78.3 | 74.1 | 84.5 | 80.0 | 76.7 | 79.0 | 73.6 | 67.0 | 77.0 | 71.8 | 68.1 | 75.5 | 68.5 | 63.0 |
| | Min.... | 56.5 | 56.7 | 57 0 | 56.4 | 56.2 | 56.8 | 55.2 | 57.2 | 56.9 | 56.8 | 55.7 | 57.5 | 57.2 | 57.5 | 58.6 |
| 5 | Max.... | 86.8 | 80.6 | 77.0 | 86.5 | 81.8 | 78.9 | 82.1 | 76.8 | 70.0 | 80.3 | 75.5 | 71.1 | 75.9 | 70.0 | 64.6 |
| | Min.... | 56.0 | 57.0 | 58.8 | 55.2 | 55.7 | 57.8 | 56.1 | 58.7 | 59.8 | 56.2 | 57.0 | 59.6 | 55.9 | 59.2 | 61.8 |
| 7 | Max.... | 82.1 | 79.8 | 75.8 | 83.1 | 80.6 | 77.1 | 81.3 | 76.6 | 70.8 | 80.3 | 75.6 | 71.7 | 78.2 | 71.3 | 68.7 |
| | Min.... | 62.1 | 67.8 | 68.0 | 64.6 | 66.9 | 68.1 | 67.2 | 67.4 | 67.4 | 67.1 | 67.4 | 67.6 | 67.2 | 66.7 | 66.8 |
| 8 | Max.... | 70.3 | 69.8 | 67.9 | 74.4 | 71.7 | 70.1 | 70.1 | 68.3 | 65.1 | 70.2 | 68.1 | 66.3 | 72.2 | 67.8 | 64.8 |
| | Min.... | 52.4 | 53.5 | 55.9 | 51.0 | 51.7 | 53.9 | 52.6 | 56.8 | 59.2 | 53.6 | 55.1 | 59.0 | 53.0 | 58.3 | 62.9 |
| 9 | Max.... | ..... | 64.1 | 63.4 | 67.4 | 65.1 | 63.9 | 64.8 | 63.7 | 61.8 | 64.3 | 61.7 | 62.2 | 64.9 | 63.1 | 63.1 |
| | Min.... | ..... | 55.7 | 57.8 | 53.7 | 54.5 | 56.9 | 54.9 | 58.4 | 59.8 | 55.8 | 57.8 | 60.0 | 56.7 | 60.5 | 61.8 |
| 10 | Max.... | ..... | 62.0 | 60.0 | 64.7 | 62.6 | 60.7 | 62.5 | 60.4 | 58.9 | 62.0 | 59.1 | 59.3 | 61.9 | 59.7 | 59.6 |
| | Min.... | ..... | 51.3 | 53.3 | 48.5 | 49.2 | 51.2 | 49.8 | 53.3 | 55 3 | 50.6 | 52.4 | 55.1 | 49.8 | 54.5 | 58.5 |
| 11 | Max.... | ..... | 73.2 | 70.1 | 78.0 | 76.3 | 73.4 | 75.3 | 70.6 | 64.7 | 73.9 | 69.8 | 68.0 | 75.5 | 68.0 | 62.6 |
| | Min.... | ..... | 57.5 | 57.2 | 58.1 | 57.5 | 57.3 | 57.2 | 57.5 | 56.7 | 58.0 | 57.0 | 57.3 | 57.8 | 57.4 | 58.8 |
| 12 | Max.... | ..... | 78.5 | 74.5 | 85.6 | 80.6 | 77.0 | 80.6 | 74.9 | 68.7 | 79.0 | 73.4 | 69.5 | 77.6 | 70.2 | 65.0 |
| | Min.... | ..... | 55.1 | 56.8 | 53.5 | 53.8 | 55.6 | 54.0 | 57.0 | 58.2 | 54.9 | 56.1 | 58.3 | 54.5 | 58.2 | 61.4 |
| 14 | Max.... | 74.4 | 70.4 | 68.7 | 75.4 | 71.5 | 69.7 | 70.7 | 68.2 | 65.2 | 70.4 | 67.5 | 66.1 | 70.5 | 67.0 | 64.6 |
| | Min.... | 55.1 | 56.3 | 58.3 | 54.5 | 54 9 | 57.1 | 55.2 | 58.5 | 60.1 | 56.5 | 58.1 | 60.8 | 55.5 | 60.0 | 63.2 |
| 15 | Max.... | 72.8 | 70.5 | 68.7 | 74.6 | 73.0 | 70.8 | 70.8 | 68.7 | 65.1 | 71.2 | 68.1 | 66.2 | 72.2 | 67.4 | 64.2 |
| | Min.... | 58.0 | 59.2 | 60.4 | 57.9 | 58.5 | 59.7 | 58.4 | 60.5 | 60.6 | 59.3 | 58.9 | 61.2 | 59.3 | 61.1 | 62.5 |
| 16 | Max.... | 68.0 | 68.8 | 68.0 | 69.5 | 70.0 | 69.7 | 68.0 | 67.4 | 63.9 | 69.0 | 67.6 | 65.6 | 69.7 | 66.2 | 64.5 |
| | Min.... | 57.5 | 57.7 | 59.0 | 57.5 | 57.3 | 58.2 | 56.5 | 59.0 | 59.6 | 57.9 | 58.1 | 60.1 | 57.5 | 59.8 | 62.6 |
| 17 | Max.... | 78.5 | 76.3 | 73.0 | 85.4 | 81.5 | 78.3 | 75.9 | 72.6 | 67.5 | 76.5 | 71.6 | 69.2 | 77.2 | 70.6 | 65.9 |
| | Min.... | 56.4 | 57.5 | 59.0 | 56.4 | 56.9 | 58.1 | 56.5 | 59.1 | 59.5 | 57.7 | 57.8 | 60.3 | 57.5 | 60 0 | 62.3 |
| 18 | Max.... | 73.0 | 70.7 | 68.7 | 75.2 | 71.9 | 70.9 | 69.9 | 68.0 | 64.7 | 70.2 | 67.7 | 65.7 | 70.9 | 67.1 | 65.4 |
| | Min.... | 56.2 | 57.4 | 59.0 | 56.6 | 57.0 | 58.9 | 55.5 | 58.8 | 60.0 | 56.8 | 57.8 | 60.7 | 56.4 | 60.4 | 63.0 |
| 19 | Max.... | 71.6 | 68.7 | 67.4 | 75.9 | 71.8 | 70.5 | 69.3 | 67.4 | 65.0 | 69.7 | 66.8 | 65.7 | 70.6 | 67.3 | 65.5 |
| | Min.... | 58.7 | 60.4 | 62.0 | 58.9 | 60.0 | 61.8 | 59.1 | 62.2 | 62.4 | 59.9 | 61.0 | 62.5 | 61.3 | 63.5 | 64.3 |
| 21 | Max.... | 77.5 | 74.6 | 70.8 | 80.4 | 77.6 | 74.0 | 74.5 | 70.0 | 66.0 | 74.6 | 70.1 | 67.1 | 72.0 | 68.7 | 65.5 |
| | Min.... | 57.3 | 57.9 | 59.5 | 56.8 | 56.9 | 58.5 | 56.7 | 59.5 | 60.7 | 57.7 | 58.9 | 61.2 | 56.9 | 60.9 | 64.2 |
| 22 | Max.... | 78.0 | 74.9 | 72.8 | 81.3 | 77.8 | 75.4 | 75.3 | 72.6 | 68.0 | 74.9 | 71.7 | 69.2 | 72.5 | 68.5 | 65.8 |
| | Min.... | 58.4 | 59.1 | 60.5 | 58.3 | 58.3 | 59.8 | 58.0 | 60.6 | 61.2 | 59.2 | 60.0 | 61.8 | 58.7 | 61.5 | 63.8 |
| 23 | Max.... | 83.1 | 79.0 | 75.5 | 84.6 | 80.7 | 77.8 | 80.5 | 75.8 | 69.5 | 78.7 | 74.5 | 69.9 | 79.2 | 71.2 | 65.4 |
| | Min.... | 51.5 | 53.9 | 57.3 | 50.8 | 52.3 | 55.6 | 52.3 | 57.3 | 59.6 | 53.1 | 55.8 | 59.4 | 51.4 | 57.8 | 62.1 |
| 24 | Max.... | 74.1 | 71.9 | 69.1 | 75.3 | 73.0 | 70.3 | 72.4 | 69.0 | 65.0 | 71.7 | 66.8 | 65.6 | 71.9 | 65.8 | 63.7 |
| | Min.... | 55.5 | 57.5 | 60.0 | 54.6 | 56.2 | 58.7 | 56.4 | 60.3 | 61.8 | 56.5 | 58.8 | 61.5 | 54.7 | 59.9 | 62.9 |
| 25 | Max.... | 84.8 | 80.5 | 76.8 | 84.6 | 81.7 | 78.4 | 81.5 | 76.9 | 69.9 | 80.3 | 75.4 | 70.8 | 81.1 | 72.6 | 66.0 |
| | Min.... | 57.9 | 59.1 | 60.6 | 57.7 | 58.4 | 59.9 | 57.9 | 60.6 | 61.1 | 58.5 | 59.5 | 61.0 | 57.6 | 60.0 | 62.4 |
| 26 | Max.... | 92.4 | 86.1 | 81.5 | 90.1 | 86.2 | 82.6 | 86.9 | 81.4 | 74.1 | 85.3 | 80.2 | 75.0 | 85.0 | 76.6 | 69.2 |
| | Min.... | 57.0 | 59.1 | 61.5 | 56.5 | 57.9 | 60.6 | 57.1 | 61.5 | 62.8 | 57.8 | 60.0 | 62.5 | 56.6 | 61.5 | 64.6 |
| 28 | Max.... | 92.9 | 87.0 | 83.5 | 88.9 | 85.8 | 83.1 | 88.0 | 83.4 | 77.0 | 86.6 | 82.0 | 78.0 | 84.0 | 77.9 | 71.9 |
| | Min.... | 62.6 | 63.5 | 65.5 | 61.7 | 62.6 | 64.8 | 62.3 | 65.6 | 67.0 | 62.0 | 63.8 | 66.4 | 60.8 | 65.3 | 68.5 |
| 29 | Max.... | 72.8 | 71.5 | 70.3 | 73.1 | 71.7 | 70.5 | 70.9 | 70.6 | 68.9 | 72.0 | 69.9 | 69.4 | 72.4 | 69.4 | 69.7 |
| | Min.... | 65.1 | 66.3 | 68.1 | 64.5 | 65.6 | 67.4 | 63.8 | 68 2 | 68.6 | 64.7 | 66.5 | 68.4 | 63.9 | 67.0 | 68.4 |
| 30 | Max.... | 87.5 | 82.8 | 80.0 | 90.2 | 85.7 | 83.4 | 83.3 | 80.5 | 74.5 | 83.1 | 79.5 | 75.8 | 85.8 | 78.9 | 72.0 |
| | Min.... | 61.7 | 61.9 | 63.1 | 60 6 | 60.8 | 62.0 | 60.4 | 63.7 | 64.3 | 62.0 | 62.9 | 64.4 | 61.5 | 63.8 | 66.6 |
| Ave. | Max | c77.73 | 73.87 | 71.27 | 78.25 | 75.40 | 73.10 | 74.40 | 71.25 | 66.82 | 73.86 | 70.19 | 67.73 | 73.95 | 68.38 | 65.07 |
| | Min | c57.61 | 57.90 | 59.84 | 56.73 | 57.35 | 59.01 | 57.07 | 59.93 | 60.72 | 57.82 | 58.78 | 60.88 | 57.42 | 60.36 | 62.67 |
| | Range | 20.12 | 15.97 | 11.43 | 21.52 | 18.05 | 14.09 | 17.33 | 11.33 | 6.10 | 16.04 | 11.41 | 6.85 | 16.53 | 8.02 | 2.40 |

cAverage of 22 days instead of 26 as the rest of the averages.

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TABLE 70.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, JULY, 1915.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 Max.... | 94.3 | 86.8 | 79.9 | 95.8 | 90.0 | 83.0 | 88.3 | 79.8 | 75.8 | 88.4 | 79.5 | 76.7 | 89.2 | 77.6 | 75.9 |
| 1 Min.... | 64.3 | 64.6 | 66.0 | 63.5 | 63.7 | 65 3 | 62.2 | 66.7 | 67.0 | 64.7 | 65.5 | 67.2 | 64.8 | 67.8 | 70 1 |
| 2 Max.... | 83.0 | 79.6 | 75.9 | 87.8 | 83.5 | 79.9 | 80.8 | 76.0 | 73.0 | 81.5 | 76.5 | 74.8 | 81.7 | 75.8 | 72.9 |
| 2 Min.... | 64.1 | 65.2 | 66.6 | 63.5 | 64.4 | 66.0 | 64.6 | 67.1 | 67.5 | 65.1 | 65.6 | 67.7 | 64.7 | 67.2 | 70.0 |
| 3 Max.... | 83.7 | 81.6 | 78.8 | 84.9 | 83.4 | 80.9 | 80.6 | 78.0 | 72.9 | 80.6 | 77.0 | 74.5 | 78.9 | 74.5 | 71.6 |
| 3 Min.... | 61.4 | 62.0 | 63.8 | 60.8 | 61.5 | 63.4 | 59 0 | 64.2 | 65.6 | 62.2 | 63.3 | 66 1 | 62.3 | 66.7 | 69 8 |
| 5 Max.... | 68.5 | 67.8 | 66.8 | 71.0 | 70.5 | 69.3 | 66.0 | 67.0 | 64.7 | 69.4 | 67.6 | 66.5 | 66.6 | 65.6 | 65.3 |
| 5 Min.... | 55.9 | 57.2 | 59.2 | 55.4 | 56.4 | 58.1 | 54.5 | 59.5 | 60.8 | 57.2 | 58.2 | 61.0 | 57.2 | 60 8 | 64.5 |
| 6 Max.... | 81.3 | 77.0 | 74.3 | 83.8 | 79.4 | 76.9 | 74.1 | 73.5 | 68.5 | 78.0 | 73.1 | 70.8 | 74.0 | 69.0 | 65.4 |
| 6 Min.... | 54.7 | 55.0 | 56.8 | 54.0 | 54.0 | 55.7 | 52.4 | 57.0 | 58.6 | 55.2 | 56.4 | 59.1 | 53.0 | 57 8 | 62.4 |
| 7 Max.... | 66.2 | 66.4 | 66.5 | 66.2 | 66.3 | 66.7 | 63.0 | 66.2 | 64.8 | 66.5 | 65.3 | 66.0 | 66.1 | 65.2 | 65.2 |
| 7 Min.... | 64.7 | 64.1 | 64.7 | 63.1 | 63.6 | 64.4 | 60.5 | 64.3 | 63.8 | 63.9 | 63.1 | 65.0 | 62.4 | 63.6 | 65.1 |
| 8 Max.... | 77.2 | 74.6 | 72.1 | 81.6 | 80.0 | 77.2 | 74.5 | 73.4 | 68.3 | 75.0 | 71.0 | 69.1 | 73.6 | 69.2 | 65.8 |
| 8 Min.... | 59.7 | 60.4 | 61.5 | 59.1 | 59.7 | 61.0 | 56.4 | 61.2 | 61.3 | 60.6 | 60.2 | 62.3 | 60.1 | 61 5 | 63 0 |
| 9 Max.... | 92.1 | 84.5 | 80.9 | 94.5 | 88.1 | 84.1 | 83.8 | 80.0 | 73.7 | 82.9 | 76.6 | 73.9 | 81.4 | 74.8 | 68.7 |
| 9 Min.... | 57.4 | 58.0 | 59.8 | 57.0 | 57.1 | 59.3 | 54.6 | 60.4 | 61.6 | 57 9 | 58.5 | 61.8 | 55.4 | 60.0 | 63 8 |
| 10 Max.... | 93.2 | 86.3 | 82.5 | 93.4 | 88.1 | 84.4 | 87.6 | 81.6 | 75.9 | 84.8 | 79.7 | 76.0 | 84.5 | 77.3 | 71.4 |
| 10 Min.... | 64.1 | 64.9 | 66.4 | 63.8 | 64.3 | 66.0 | 62.3 | 66 2 | 66.5 | 63.5 | 64.8 | 66.3 | 63.0 | 65.6 | 67.5 |
| 12 Max.... | 92.3 | 87.8 | 84.4 | 91.5 | 88.4 | 85.8 | 88.3 | 84.1 | 78.5 | 85.4 | ..... | 78.5 | 87.2 | 80.2 | 75.5 |
| 12 Min.... | 69.1 | 69.4 | 70.1 | 68.8 | 68.9 | 69.7 | 68.2 | 70.0 | 69.8 | 68.4 | ..... | 69.6 | 68.7 | 69.9 | 71.3 |
| 13 Max.... | 96.5 | 90.6 | 86.8 | 94.2 | 90.5 | 87.6 | 91.6 | 86.6 | 80.4 | 88.3 | ..... | 80.4 | 90.7 | 82.6 | 77.2 |
| 13 Min.... | 67.9 | 68.5 | 70.0 | 67.1 | 67.7 | 69.5 | 67.2 | 69.9 | 70.6 | 66.7 | ..... | 70.0 | 66.8 | 70.3 | 72.8 |
| 14 Max.... | 90.1 | 85.6 | 81.6 | 88.9 | 85.5 | 82.2 | 85.3 | 81.6 | 77.9 | 84.4 | ..... | 77.6 | 86.3 | 80.1 | 76.9 |
| 14 Min.... | 71.3 | 71.7 | 72.8 | 70.6 | 70.9 | 72.3 | 69.4 | 72.8 | 72.9 | 70.0 | ..... | 72.2 | 70.6 | 73.1 | 74 9 |
| 15 Max.... | 77.5 | 77.1 | 76.2 | 77.7 | 77.6 | 77.0 | 75.6 | 76.8 | 73.9 | 77.6 | ..... | 74.7 | 79.3 | 76.4 | 74.8 |
| 15 Min.... | 70.8 | 71 2 | 72.2 | 70.3 | 70.6 | 71.7 | 69.4 | 72.5 | 72.3 | 71.0 | ..... | 72.3 | 71.8 | 73.5 | 73.3 |
| 16 Max.... | 85.6 | 83.6 | 80.9 | 88.5 | 86.7 | 84.2 | 83.3 | 82.0 | 77.1 | 85.6 | 82.3 | 78.9 | 86.5 | 80.5 | 76.6 |
| 16 Min.... | 70.2 | 69.6 | 70.0 | 69.7 | 69.2 | 69.5 | 67.5 | 70.5 | 70.2 | 70.1 | 69.9 | 70.6 | 70.2 | 71.2 | 73.0 |
| 17 Max.... | 93.9 | 89.5 | 85.9 | 95.1 | 91.2 | 88.4 | 88.6 | 86.0 | 80.1 | 88.8 | 85.0 | 81.2 | 89.8 | 82.7 | 77.6 |
| 17 Min.... | 68.3 | 68.7 | 70.1 | 67.6 | 68.1 | 69.6 | 66.6 | 70.6 | 71.2 | 69.0 | 70.3 | 71.8 | 69.5 | 72.6 | 74.8 |
| 19 Max.... | 78.6 | 76.9 | 75.9 | 79.6 | 78.3 | 77.5 | 76.5 | 76.4 | 73.6 | 80.2 | 78.1 | 75.8 | 79.2 | 76.4 | 74.4 |
| 19 Min.... | 65.4 | 67.0 | 69.1 | 64.7 | 66.0 | 68.0 | 65 1 | 69.6 | 70.5 | 66.8 | 68.8 | 70.6 | 67.3 | 71.0 | 72.1 |
| 20 Max.... | 78.3 | 77.3 | 75.4 | 80.3 | 79.3 | 77.5 | 77.3 | 76.1 | 71.9 | 79.6 | 77.2 | 74.2 | 76.3 | 73.5 | 71.5 |
| 20 Min.... | 63.2 | 64.4 | 66.1 | 62.4 | 63.5 | 65.4 | 62.2 | 66.7 | 67.6 | 64.9 | 66.8 | 68.7 | 64.4 | 68 1 | 69.8 |
| 21 Max.... | 75.6 | 76.4 | 74.0 | 76.3 | 76.9 | 75.7 | 75.3 | 74.3 | 71.0 | 76.6 | 74.4 | 72.1 | 76.5 | 72.4 | 69.7 |
| 21 Min.... | 59.5 | 60.8 | 63.0 | 58 2 | 59.2 | 61.8 | 58.4 | 63.5 | 65.2 | 61.0 | 63.2 | 65.7 | 58.8 | 64.1 | 68.7 |
| 22 Max.... | 84.5 | 82.1 | 78.8 | 86.8 | 84.4 | 81.5 | 82.6 | 79.8 | 73.8 | 83.7 | 80.1 | 75.8 | 82.9 | 76.3 | 68.7 |
| 22 Min.... | 57.4 | 58.5 | 61.1 | 55.8 | 56.8 | 59.1 | 55.8 | 61.3 | 63.2 | 58.3 | 60.8 | 63.3 | 56.5 | 62.3 | 66.9 |
| 23 Max.... | 92.6 | 86.2 | 82.9 | 93.5 | 88.0 | 85.3 | 86.2 | 82.5 | 76.5 | 85.5 | 81.3 | 77.6 | 85.7 | 78.5 | 72.9 |
| 23 Min.... | 60.8 | 62.0 | 64.1 | 59.4 | 60.5 | 62.8 | 60.0 | 64.4 | 66.0 | 61.7 | 63.8 | 66.3 | 59.8 | 65.0 | 68.8 |
| 24 Max.... | 83.8 | 80.1 | 76.4 | 84.1 | 81.2 | 77.8 | 79.6 | 76.0 | 73.2 | 79.4 | 75.2 | 73.6 | 80.1 | 74.5 | 72.1 |
| 24 Min.... | 65 0 | 65.9 | 67.5 | 64.0 | 64.9 | 66 8 | 63.6 | 67.3 | 68.2 | 64.4 | 66.1 | 68.0 | 63.6 | 67.4 | 70.1 |
| 26 Max.... | 82.1 | 80.7 | 78.1 | 83.9 | 83.0 | 80.6 | 80.7 | 78.5 | 73.6 | 81.5 | 78.6 | 75.4 | 82.2 | 76.5 | 72.1 |
| 26 Min.... | 64.5 | 65.4 | 66.6 | 63.9 | 64.8 | 66 2 | 63.8 | 67.0 | 67.3 | 65.8 | 66 8 | 68.0 | 65.8 | 68.0 | 68 7 |
| 27 Max.... | 72.4 | 71.2 | 70.0 | 72.7 | 71.6 | 70.5 | 70.6 | 70.1 | 68.6 | 71.5 | 69.9 | 69.4 | 71.8 | 69.9 | 70.0 |
| 27 Min.... | 63.6 | 64.7 | 66.2 | 62.7 | 63.7 | 65.6 | 63 0 | 66.6 | 67.2 | 64.5 | 66.1 | 67.7 | 63.8 | 67.1 | 68.8 |
| 28 Max.... | 74.9 | 73.8 | 72.3 | 75.1 | 74.5 | 73.4 | 73.1 | 72.5 | 69.6 | 73.9 | 72.3 | 70.6 | 74.9 | 71.8 | 69.2 |
| 28 Min.... | 66.6 | 66.4 | 66.8 | 66.3 | 66.2 | 66.7 | 65 4 | 67.0 | 66.4 | 66.8 | 66.9 | 67.1 | 67.0 | 67.4 | 68.1 |
| 29 Max.... | 78.2 | 76.2 | 73.8 | 78.2 | 76.9 | 74.9 | 76.7 | 74.1 | 70.2 | 77.1 | 74.1 | 71.6 | 78.3 | 73.0 | 68.9 |
| 29 Min.... | 65.6 | 65.6 | 66.0 | 65.1 | 65.0 | 65.8 | 64.3 | 66.3 | 66.1 | 65.9 | 66.0 | 66.8 | 65.8 | 66.8 | 67.5 |
| 30 Max.... | 87.1 | 82.1 | 78.7 | 88.5 | 84.2 | 80.8 | 81.7 | 79.0 | 74.9 | 84.4 | 80.4 | 77.4 | 84.5 | 78.8 | 71.2 |
| 30 Min.... | 70.0 | 69.6 | 69.8 | 69.8 | 69.6 | 70.0 | 68.8 | 69.9 | 68.9 | 69.9 | 69.7 | 69.8 | 70.6 | 70.4 | 69.2 |
| 31 Max.... | 85.5 | 83.5 | 80.5 | 85.4 | 84.1 | 82.0 | 83.1 | 80.6 | 75.8 | 84.0 | 80.8 | 77.6 | 85.8 | 79.7 | 72.2 |
| 31 Min.... | 69.4 | 69 8 | 70 6 | 69.0 | 69.6 | 70 5 | 68.6 | 70.8 | 70.4 | 70.2 | 70.9 | 71.5 | 70.6 | 71.8 | 70.6 |
| Ave. Max.. | 83.29 | 80.19 | 77.41 | 84.41 | 81.91 | 79.45 | 79.80 | 77.50 | 73.27 | 80.54 | 76.36 | 74.47 | 80.52 | 75.28 | 71.62 |
| Ave. Min.. | 63.82 | 64.84 | 66.18 | 63.54 | 64.07 | 65.56 | 62.73 | 66.42 | 66.91 | 65.03 c | 64.88 | 67.28 | 64.24 | 67.07 | 69.10 |
| Ave. Range | 19.41 | 15.35 | 11.23 | 20.87 | 16.84 | 13.89 | 17.07 | 11.08 | 6.36 | 15.51 | 11.50 | 7.19 | 16.28 | 8.21 | 2.52 |

cAverage of 23 days only instead of 27 as the rest of the figures.

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TABLE 71.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, AUGUST, 1915.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 2 Max.... | 77.0 | 74.6 | 74.7 | 76.8 | 74.1 | 74.7 | 74.6 | 74.8 | 73.4 | 75.0 | 74.5 | 74.2 | 76.4 | 75.7 | 76.1 |
| 2 Min.... | 69.8 | 70.7 | 72.1 | 68.9 | 69.8 | 71.6 | 69.3 | 72.1 | 72.3 | 70.5 | 72 1 | 73.3 | 70 8 | 73.8 | 74.6 |
| 3 Max.... | 75.9 | 75.3 | 73.9 | 75.9 | 75.6 | 74.8 | 75.4 | 74.4 | 71.2 | 76.3 | 74.6 | 72.8 | 77.3 | 74.0 | 72.5 |
| 3 Min.... | 66.9 | 67.8 | 68.8 | 66.3 | 67.0 | 68.3 | 67.0 | 69 0 | 68.9 | 67.9 | 68 8 | 69.7 | 68.8 | 70.6 | 71.4 |
| 4 Max.... | 73.3 | 71.0 | 69.6 | 74.1 | 72.0 | 70.2 | 71.3 | 70.0 | 68.7 | 72.4 | 70.0 | 69.8 | 71.7 | 70.5 | 70.8 |
| 4 Min.... | 64.1 | 65.1 | 66.3 | 63.5 | 64.4 | 66.0 | 64.1 | 66 6 | 67.1 | 65.0 | 66.3 | 67.7 | 65.7 | 68.4 | 69.5 |
| 5 Max.... | 63.5 | 63.6 | 64.1 | 63.2 | 63.4 | 64.0 | 62.8 | 64.3 | 64.1 | 63.8 | 64.2 | 64.8 | 63.9 | 64.9 | 67.8 |
| 5 Min.... | 60.5 | 61.4 | 62.8 | 59.6 | 60.5 | 62.1 | 60.0 | 63.0 | 63 9 | 61.4 | 62.9 | 64.6 | 61.2 | 64.6 | 66 5 |
| 6 Max.... | 72.8 | 69.3 | 68.5 | 73.5 | 70.5 | 69.4 | 69.8 | 68.5 | 66.0 | 70.9 | 68.8 | 67.3 | 70.3 | 67.9 | 66.4 |
| 6 Min.... | 60.1 | 60 5 | 61.5 | 59.6 | 59.9 | 60.8 | 59.5 | 61.5 | 61.8 | 60 6 | 61.3 | 62.3 | 60.3 | 62.5 | 64.7 |
| 7 Max.... | 73.5 | 71.7 | 70.4 | 74.4 | 73.4 | 72.2 | 71.1 | 70.2 | 67.0 | 72.0 | 70.5 | 68.5 | 72.8 | 69.1 | 66.3 |
| 7 Min.... | 58.8 | 59.6 | 61.0 | 58.0 | 58.7 | 60.3 | 58.1 | 60.9 | 61.6 | 59.2 | 60.6 | 62.0 | 58.9 | 62.0 | 62.0 |
| 9 Max.... | 87.0 | 82.8 | 79.8 | 89.8 | 85.3 | 82.7 | 80.3 | 77.8 | 72.6 | 83.2 | 79.9 | 76.0 | 84.3 | 77.5 | 71.5 |
| 9 Min.... | 62.3 | 63.2 | 65.0 | 61.5 | 62.3 | 64.2 | 61.3 | 64.1 | 65.0 | 62.9 | 64.5 | 66.2 | 62.0 | 65.6 | 68.1 |
| 10 Max.... | 90.8 | 85.3 | 82.1 | 92.6 | 87.1 | 84.6 | 83.9 | 80.3 | 74.9 | 86.4 | 81.9 | 77.9 | 86.8 | 78.9 | 73.5 |
| 10 Min.... | 63.1 | 64.6 | 66.7 | 62.0 | 63.3 | 65.7 | 61.8 | 65.4 | 66.4 | 63.7 | 65 7 | 67.6 | 62.5 | 66.8 | 68.8 |
| 11 Max.... | 71.1 | 70.3 | 70.4 | 70.9 | 70.3 | 70.4 | 68.9 | 69.6 | 68.6 | 70.0 | 69.7 | 69.7 | 70.0 | 69.6 | 71.5 |
| 11 Min.... | 66.0 | 67.2 | 69.1 | 65.0 | 66.1 | 68.2 | 64.6 | 67.8 | 68 0 | 66.0 | 67.9 | 69.2 | 65.0 | 68.8 | 69.8 |
| 12 Max.... | 69.3 | 68.1 | 67.9 | 69.5 | 68.3 | 68.0 | 67.9 | 68.0 | 66.8 | 68.9 | 68.0 | 67.8 | 68.5 | 68.0 | 68.5 |
| 12 Min.... | 64.1 | 64.8 | 66.0 | 63.5 | 64.1 | 65.3 | 63.7 | 65.8 | 65.9 | 64.7 | 65.7 | 66.7 | 64.6 | 66.4 | 67.4 |
| 13 Max.... | 80.5 | 76.4 | 74.0 | 83.3 | 79.3 | 75.8 | 76.7 | 73.4 | 70.3 | 77.8 | 73.5 | 71.7 | 77.6 | 72.8 | 68.6 |
| 13 Min.... | 62.9 | 63.2 | 64.0 | 62.4 | 62.7 | 63.7 | 62.3 | 64.1 | 64.2 | 63.4 | 63 9 | 64.9 | 63.0 | 64.6 | 66.6 |
| 14 Max.... | 78.0 | 74.1 | 71.3 | 78.9 | 75.8 | 72.6 | 74.9 | 71.3 | 69.3 | 75.6 | 71.4 | 70.5 | 75.4 | 71.1 | 69.0 |
| 14 Min.... | 62.0 | 62.7 | 64.3 | 61.0 | 61.6 | 63.4 | 61.2 | 64.1 | 64.7 | 62 3 | 63.7 | 65.4 | 61.6 | 65.0 | 66 5 |
| 16 Max.... | 83.2 | 80.6 | 78.3 | 85.1 | 83.1 | 80.9 | 79.0 | 77.0 | 72.7 | 80.3 | 77.6 | 74.5 | 81.1 | 75.8 | 70.6 |
| 16 Min.... | 64.8 | 65 5 | 66 8 | 64.2 | 64.8 | 66 3 | 63.9 | 66.3 | 66.7 | 65.1 | 66.1 | 67.4 | 64.7 | 67.2 | 67 8 |
| 17 Max.... | 72.3 | 71.5 | 70.9 | 74.9 | 74.2 | 73.6 | 70.6 | 71.0 | 68.6 | 71.3 | 70.9 | 69.9 | 71.3 | 70.0 | 69.9 |
| 17 Min.... | 62.8 | 64.7 | 66.9 | 62.0 | 63.6 | 66.1 | 62.9 | 66.6 | 66 5 | 64.1 | 66.3 | 67.5 | 64 2 | 67.3 | 68 9 |
| 18 Max.... | 82.1 | 78.3 | 75.5 | 85.1 | 81.1 | 78.7 | 77.0 | 74.5 | 69.6 | 77.0 | 74.1 | 70.8 | 77.7 | 71.6 | 67.1 |
| 18 Min.... | 52 9 | 54.8 | 58.0 | 51.2 | 52.8 | 56.0 | 52.5 | 57 8 | 60.6 | 53.8 | 57 1 | 60.6 | 51.5 | 59.4 | 64 1 |
| 19 Max.... | 86.7 | 82.1 | 78.8 | 89.0 | 84.6 | 81.6 | 81.6 | 77.9 | 72.0 | 81.5 | 78.0 | 73.6 | 82.5 | 75.0 | 67.8 |
| 19 Min.... | 56.9 | 58.4 | 61.2 | 54.6 | 56.6 | 59.8 | 55.4 | 60.5 | 62.5 | 57.0 | 59.8 | 62.6 | 55.1 | 61.5 | 65.5 |
| 20 Max.... | 78.3 | 74.5 | 72.8 | 79.1 | 75.9 | 74.0 | 75.0 | 71.9 | 69.0 | 74.8 | 71.6 | 70.2 | 74.8 | 70.7 | 67.8 |
| 20 Min.... | 59.3 | 61.4 | 63.7 | 57.8 | 59.6 | 62.4 | 58.5 | 62.6 | 64.3 | 59.5 | 62.4 | 64.6 | 58.0 | 63.5 | 65.6 |
| 21 Max.... | 66.2 | 65.9 | 65.7 | 66.1 | 65.9 | 65.8 | 65.4 | 65.6 | 64.8 | 66.3 | 65.6 | 65.7 | 66.0 | 65.6 | 66.9 |
| 21 Min.... | 63.8 | 64.2 | 65.4 | 63.2 | 63.8 | 65.0 | 63.2 | 64.8 | 64.5 | 64.0 | 64.6 | 65.5 | 64.0 | 65.1 | 66.0 |
| 23 Max.... | 84.1 | 79.6 | 76.9 | 87.3 | 82.6 | 80.4 | 78.9 | 75.9 | 71.0 | 78.9 | 76.0 | 72.6 | 80.1 | 73.9 | 68.4 |
| 23 Min.... | 59.2 | 60.5 | 62.1 | 58.3 | 59.5 | 61.5 | 58.7 | 62.0 | 63.0 | 59.9 | 61.6 | 63.5 | 58.7 | 62.6 | 65 6 |
| 24 Max.... | 77.5 | 74.3 | 73.0 | 78.6 | 75.9 | 74.3 | 74.3 | 72.0 | 69.8 | 74.5 | 71.8 | 70.9 | 73.8 | 71.3 | 68.2 |
| 24 Min.... | 65 5 | 66.2 | 67.3 | 65.2 | 66.1 | 67.4 | 65.4 | 67.0 | 66.7 | 66.0 | 66.8 | 67.5 | 66.1 | 67.4 | 67.5 |
| 25 Max.... | 71.8 | 71.0 | 69.8 | 72.6 | 72.3 | 71.1 | 70.1 | 68.9 | 66.1 | 70.0 | 68.7 | 67.1 | 70.8 | 67.5 | 66.7 |
| 25 Min.... | 60.7 | 62.2 | 63.9 | 59.8 | 61.3 | 63.1 | 60.4 | 63.2 | 63.6 | 61.3 | 63.0 | 64.4 | 60.9 | 63.6 | 65.0 |
| 26 Max.... | 77.4 | 72.9 | 71.5 | 79.1 | 75.4 | 73.5 | 74.0 | 70.8 | 67.5 | 74.0 | 70.6 | 68.7 | 74.4 | 69.8 | 66.4 |
| 26 Min.... | 55.6 | 58.0 | 60.6 | 54.4 | 56.6 | 59.5 | 55.1 | 59.8 | 61.3 | 56.4 | 59.4 | 61.8 | 56.0 | 60.9 | 63.8 |
| 27 Max.... | 78.3 | 74.4 | 71.8 | 78.9 | 75.4 | 73.5 | 73.4 | 70.8 | 66.8 | 73.9 | 70.9 | 67.9 | 74.9 | 69.2 | 64.8 |
| 27 Min.... | 50.8 | 53.9 | 57.4 | 48.7 | 51.5 | 55.5 | 50.4 | 56.3 | 59.0 | 51 4 | 55.5 | 59 0 | 49.8 | 57.6 | 61.8 |
| 28 Max.... | 81.1 | 76.9 | 74.0 | 81.5 | 78.1 | 75.8 | 75.9 | 73.1 | 68.1 | 76.3 | 73.3 | 69.6 | 78.0 | 70.6 | 65.9 |
| 28 Min.... | 53.0 | 55.3 | 58.2 | 51.1 | 53.2 | 56.6 | 51.7 | 56.9 | 59.1 | 53.0 | 56.2 | 59.3 | 51.1 | 57.8 | 62.1 |
| 30 Max.... | 71.2 | 69.5 | 67.7 | 71.4 | 70.2 | 68.8 | 68.5 | 67.1 | 64.0 | 68.9 | 67.1 | 65.1 | 70.3 | 66.0 | 63.4 |
| 30 Min.... | 54.5 | 56.8 | 59.1 | 54.0 | 56.0 | 58.4 | 53.8 | 58.0 | 59.8 | 54.9 | 57.6 | 60.0 | 54.8 | 59.5 | 61 5 |
| 31 Max.... | 76.5 | 71.7 | 69.4 | 76.5 | 72.7 | 70.9 | 71.4 | 68.7 | 64.7 | 72.2 | 68.8 | 66.1 | 72.5 | 66.9 | 63.1 |
| 31 Min.... | 50.5 | 52.9 | 55 7 | 48.8 | 51 0 | 53.4 | 49 7 | 54.6 | 57.1 | 50 6 | 53.9 | 57.0 | 49.6 | 55.7 | 60.4 |
| Ave. Max. | 78.90 | 74.07 | 72.42 | 78.01 | 75.48 | 73.94 | 73.57 | 71.84 | 68.75 | 74.32 | 72.00 | 70.14 | 74.74 | 70.92 | 68.45 |
| Ave. Min. | 60.42 | 61.76 | 63.61 | 59.41 | 60.65 | 62.75 | 59.79 | 63.12 | 64.03 | 60.95 | 62.84 | 64.63 | 60.34 | 64.17 | 66.18 |
| Ave. Range | 18.48 | 12.31 | 8.81 | 18.60 | 14.83 | 11.19 | 13.78 | 8.72 | 4.72 | 13.37 | 9.16 | 5.51 | 14.40 | 6.75 | 2.27 |

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TABLE 72.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, SEPTEMBER, 1915.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 Max.... | 80.0 | 75.4 | 72.5 | 79.9 | 76.7 | 74.3 | 75.5 | 71.9 | 67.0 | 75.7 | 72.2 | 68.7 | 76.6 | 69.8 | 65.0 |
| 1 Min.... | 53.5 | 55.7 | 58.1 | 52.5 | 54.4 | 57.3 | 52.8 | 57.1 | 58.7 | 53.6 | 56.6 | 59.0 | 52.5 | 58.0 | 61.5 |
| 2 Max.... | 83.3 | 78.9 | 75.5 | 82.8 | 79.8 | 77.2 | 78.8 | 75.0 | 69.5 | 78.9 | 75.3 | 71.3 | 80.4 | 73.0 | 66.9 |
| 2 Min.... | 55.6 | 57.9 | 60.3 | 54.8 | 56.8 | 59.6 | 54.9 | 59.1 | 60.8 | 55.8 | 58.5 | 61.1 | 54.7 | 60.0 | 63.2 |
| 3 Max.... | 78.7 | 76.3 | 74.4 | 78.2 | 76.8 | 75.4 | 75.5 | 73.5 | 69.3 | 75.5 | 73.6 | 70.9 | 76.4 | 71.6 | 67.9 |
| 3 Min.... | 60.5 | 62.0 | 63.6 | 59.7 | 61.2 | 63.2 | 59.6 | 62.6 | 63.4 | 60.3 | 62.1 | 63.8 | 59.6 | 63.3 | 65.2 |
| 4 Max.... | 73.7 | 72.8 | 71.4 | 74.0 | 73.3 | 72.2 | 73.5 | 71.2 | 68.0 | 71.5 | 70.1 | 68.5 | 73.7 | 69.8 | 67.3 |
| 4 Min.... | 63.5 | 64.1 | 65.1 | 63.0 | 63.7 | 65.0 | 63.0 | 64.3 | 64.4 | 63.0 | 63.9 | 65.0 | 62.9 | 64.8 | 66.0 |
| 6 Max.... | 65.3 | 65.0 | 64.7 | 65.4 | 65.2 | 65.1 | 65.4 | 64.9 | 63.8 | 65.4 | 64.9 | 64.7 | 65.4 | 64.7 | 65.0 |
| 6 Min.... | 63.0 | 63.1 | 63.5 | 62.6 | 62.9 | 63.3 | 63.1 | 63.5 | 63.1 | 63.3 | 63.6 | 63.9 | 63.2 | 63.5 | 64.7 |
| 7 Max.... | 74.5 | 72.0 | 70.3 | 75.2 | 72.9 | 71.5 | 73.4 | 70.5 | 68.9 | 72.8 | 70.4 | 68.0 | 73.9 | 68.9 | 66.0 |
| 7 Min.... | 62.1 | 62.3 | 62.7 | 61.8 | 62.1 | 62.7 | 62.3 | 62.9 | 62.3 | 62.5 | 62.7 | 63.2 | 62.6 | 63.1 | 64.1 |
| 8 Max.... | 81.1 | 76.7 | 74.7 | 81.9 | 78.5 | 77.0 | 78.7 | 74.9 | 70.8 | 78.3 | 74.5 | 72.0 | 78.7 | 73.0 | 69.5 |
| 8 Min.... | 64.2 | 64.7 | 65.3 | 63.9 | 64.3 | 65.4 | 64.6 | 65.4 | 64.8 | 64.7 | 65.3 | 65.7 | 65.1 | 65.9 | 66.5 |
| 9 Max.... | 73.6 | 72.2 | 70.8 | 76.2 | 74.8 | 73.1 | 73.1 | 71.1 | 68.5 | 72.3 | 70.7 | 69.3 | 73.9 | 70.4 | 69.5 |
| 9 Min.... | 64.7 | 65.3 | 66.5 | 64.0 | 64.7 | 66.3 | 65.1 | 66.7 | 66.7 | 65.2 | 66.3 | 67.3 | 65.6 | 67.7 | 68.8 |
| 10 Max.... | 78.2 | 75.4 | 71.3 | 81.0 | 78.8 | 74.6 | 78.0 | 72.1 | 67.5 | 75.5 | 70.9 | 67.8 | 76.0 | 68.3 | 67.9 |
| 10 Min.... | 57.2 | 59.1 | 61.4 | 55.9 | 57.6 | 60.2 | 58.1 | 61.5 | 62.7 | 58.4 | 61.0 | 63.1 | 57.8 | 62.6 | 66.0 |
| 11 Max.... | 75.4 | 73.4 | 71.1 | 75.8 | 74.0 | 72.4 | 74.8 | 71.7 | 68.1 | 73.9 | 71.3 | 69.2 | 75.9 | 70.5 | 67.4 |
| 11 Min.... | 63.5 | 63.7 | 64.2 | 63.3 | 63.5 | 64.1 | 63.8 | 64.3 | 64.0 | 63.8 | 64.1 | 64.5 | 63.8 | 64.5 | 65.8 |
| 13 Max.... | 83.3 | 79.6 | 77.5 | 88.9 | 84.2 | 81.8 | 81.3 | 78.4 | 73.7 | 80.6 | 78.1 | 75.2 | 80.6 | 75.7 | 71.8 |
| 13 Min.... | 66.0 | 66.4 | 67.2 | 65.5 | 66.0 | 66.9 | 66.3 | 67.4 | 66.9 | 66.4 | 67.1 | 67.8 | 66.8 | 68.2 | 69.0 |
| 14 Max.... | 89.1 | 83.8 | 81.3 | 92.1 | 87.8 | 84.5 | 86.8 | 82.2 | 77.1 | 85.3 | 81.2 | 78.1 | 83.0 | 78.2 | 74.0 |
| 14 Min.... | 68.2 | 68.7 | 69.3 | 68.1 | 68.7 | 69.8 | 69 0 | 69.9 | 69.3 | 68.9 | 69.6 | 70.0 | 69.2 | 70.1 | 70.9 |
| 15 Max.... | 83.9 | 79.8 | 77.2 | 84.8 | 81.6 | 78.5 | 82.0 | 77.7 | 74.8 | 80.1 | 76.5 | 75.4 | 80.2 | 76.1 | 74.0 |
| 15 Min.... | 70.1 | 70.9 | 71.7 | 69.9 | 70.6 | 71.8 | 70.8 | 72.0 | 71.6 | 70.7 | 71.5 | 72.3 | 70.6 | 71.8 | 72 5 |
| 16 Max.... | 83.0 | 79.2 | 75.7 | 85.6 | 82.1 | 78.2 | 80.1 | 75.7 | 73.4 | 81.3 | 78.4 | 74.7 | 80.5 | 75.4 | 73.4 |
| 16 Min.... | 67 5 | 68.2 | 69.3 | 66.9 | 67.5 | 68.8 | 68.1 | 69.3 | 69.5 | 68.0 | 68.9 | 69.8 | 68.0 | 69.7 | 71 2 |
| 17 Max.... | 78.0 | 75.2 | 74.3 | 78.9 | 76.7 | 76.0 | 77.1 | 74.5 | 71.7 | 76.1 | 74.7 | 73.3 | 77.8 | 74.7 | 72.5 |
| 17 Min.... | 64.5 | 65.6 | 67.3 | 63.5 | 64.6 | 66.3 | 65.2 | 67.4 | 68 2 | 65 5 | 67.2 | 68.9 | 65.6 | 68.9 | 70 6 |
| 20 Max.... | 75.4 | 72.5 | 69.9 | 77.0 | 74.7 | 71.7 | 74.2 | 70.2 | 67.9 | 73.0 | 69.8 | 68.5 | 72.7 | 68.6 | 68.5 |
| 20 Min.... | 59.9 | 61.5 | 63.4 | 59.0 | 60.7 | 62.8 | 61.2 | 63.7 | 64.6 | 61.2 | 63.1 | 64.8 | 60.7 | 64 9 | 67 3 |
| 21 Max.... | 61.4 | 60.3 | 61.0 | 62.1 | 61.5 | 62.0 | 60.9 | 61.2 | 60.5 | 60.5 | 60.9 | 61.1 | 61.3 | 61.5 | 63.8 |
| 21 Min.... | 49.7 | 52.7 | 56 3 | 49.0 | 51.3 | 54.7 | 51.4 | 56 5 | 59.0 | 51.6 | 55.8 | 59.4 | 52.3 | 58.9 | 61.8 |
| 22 Max.... | 71.5 | 66.2 | 65.3 | 74.3 | 69.2 | 67.7 | 68.5 | 65.9 | 62.5 | 67.5 | 65.0 | 62.6 | 67.6 | 63.4 | 60.8 |
| 22 Min.... | 44.5 | 47.6 | 48 0 | 42.0 | 45.3 | 48.7 | 45.6 | 50.5 | 53.6 | 45.4 | 50.0 | 53.7 | 45.7 | 52.1 | 57.6 |
| 23 Max.... | 70.2 | 65.7 | 63.5 | 72.9 | 68.8 | 65.3 | 68.2 | 63.6 | 61.3 | 67.0 | 63.0 | 61.7 | 64.4 | 60.8 | 59.6 |
| 23 Min.... | 48.2 | 50.1 | 52.8 | 46.4 | 48.6 | 51.6 | 49.0 | 52.8 | 54.9 | 49.1 | 52.0 | 54.8 | 48.5 | 53.5 | 57.5 |
| 24 Max.... | 78.9 | 72.9 | 71.0 | 81.0 | 76.4 | 73.7 | 76.2 | 71.5 | 67.2 | 74.3 | 70.1 | 67.5 | 74.7 | 68.7 | 64.0 |
| 24 Min.... | 57.9 | 58.5 | 59.4 | 57.5 | 58.3 | 59.4 | 58.0 | 59.0 | 59.0 | 58.1 | 58.7 | 59.5 | 57.1 | 58.3 | 59.8 |
| 25 Max.... | 78.6 | 73.5 | 70.7 | 80.5 | 76.3 | 72.8 | 76.5 | 71.1 | 67.8 | 74.5 | 70.0 | 68.0 | 74.5 | 68.6 | 65.1 |
| 25 Min.... | 59.2 | 60 0 | 61.1 | 58.8 | 59.5 | 60 8 | 59.5 | 61.0 | 61.1 | 59.2 | 60.1 | 61.2 | 58.7 | 60.5 | 62 3 |
| 27 Max.... | 58.1 | 55.5 | 56.5 | 58.3 | 55.7 | 56.3 | 56.5 | 56.6 | 56.4 | 56.4 | 56.0 | 56.8 | 55.5 | 56.5 | 58.8 |
| 27 Min.... | 46.3 | 48.5 | 51.6 | 45.5 | 46.3 | 49.6 | 48.5 | 51.5 | 54.2 | 48.3 | 50.9 | 54.3 | 46.3 | 53.3 | 56.9 |
| 28 Max.... | 64.2 | 60.4 | 59.8 | 67.4 | 63.1 | 62.5 | 61.3 | 59.9 | 57.4 | 59.8 | 58.4 | 57.4 | 61.0 | 58.1 | 56.4 |
| 28 Min.... | 42.1 | 45.1 | 48.0 | 40.5 | 42.8 | 45.3 | 43.3 | 47.5 | 50.6 | 43.8 | 47.5 | 47.5 | 42.5 | 48.6 | 53.8 |
| 29 Max.... | 67.5 | 62.9 | 61.5 | 70.1 | 65.1 | 63.9 | 64.4 | 62.0 | 58.3 | 61.7 | 59.6 | 57.7 | 62.5 | 58.6 | 56.5 |
| 29 Min.... | 40.5 | 43.8 | 47.1 | 38.6 | 41.5 | 45.4 | 41.9 | 47.4 | 49.8 | 42.2 | 46.9 | 49.5 | 41.7 | 48.4 | 52.4 |
| 30 Max.... | 66.9 | 61.8 | 60.8 | 68.6 | 64.1 | 62.6 | 64.1 | 61.0 | 58.0 | 61.6 | 58.9 | 57.4 | 61.5 | 58.0 | 55.3 |
| 30 Min.... | 43.3 | 45.7 | 48.6 | 41.5 | 43.8 | 45.6 | 45.4 | 48 5 | 50.8 | 43.9 | 47.5 | 50.2 | 42.5 | 48.6 | 52.5 |
| Ave. Max.. | 74.95 | 71.50 | 69.71 | 76.52 | 73.53 | 71.62 | 73.00 | 69.93 | 66.70 | 71.97 | 69.30 | 67.45 | 72.35 | 68.12 | 65.84 |
| Ave. Min.. | 57.44 | 58.85 | 60.48 | 56.57 | 57.88 | 59.76 | 58.02 | 60.48 | 61.36 | 58.12 | 60.01 | 61.61 | 57.76 | 61.17 | 63.52 |
| Ave. Range | 17.51 | 12.65 | 9.23 | 19.95 | 15.65 | 11.84 | 14.98 | 9.45 | 5.34 | 13.85 | 9.29 | 5.84 | 14.59 | 6.95 | 2.32 |

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TABLE 73.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, OCTOBER, 1915.

| Date— | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum, minimum. | | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 | Max. | 54.4 | 54.4 | 55.0 | 54.4 | 54.5 | 55.0 | 54.4 | 54.6 | 54.0 | 54.3 | 54.3 | 54.4 | 54.2 | 54.0 | 54.8 |
| | Min. | 50.6 | 51.8 | 53.2 | 50.0 | 51.2 | 52.9 | 50.8 | 52.8 | 53.2 | 50.6 | 52.0 | 53.2 | 50.4 | 52.8 | 54.2 |
| 2 | Max. | 65.6 | 62.6 | 61.9 | 66.7 | 63.2 | 63.2 | 62.6 | 61.8 | 58.6 | 62.4 | 61.0 | 59.4 | 64.7 | 60.8 | 57.0 |
| | Min. | 50.9 | 51.8 | 52.9 | 50.1 | 51.1 | 52.5 | 51.0 | 52.5 | 52.8 | 51.2 | 52.2 | 53.1 | 51.2 | 52.5 | 54.1 |
| 4 | Max. | 64.0 | 63.0 | 61.9 | 64.5 | 63.8 | 62.8 | 63.5 | 61.6 | 59.9 | 63.0 | 61.5 | 60.6 | 63.7 | 61.2 | 59.8 |
| | Min. | 58.4 | 58.5 | 58.8 | 58.1 | 58.5 | 59.0 | 58.3 | 58.5 | 57.8 | 58.3 | 58.3 | 58.3 | 58.6 | 58.4 | 58.6 |
| 5 | Max. | 56.6 | 56.0 | 56.4 | 56.9 | 56.3 | 56.7 | 55.4 | 55.6 | 55.0 | 54.5 | 54.7 | 55.2 | 55.6 | 55.7 | 57.5 |
| | Min. | 49.3 | 51.5 | 53.7 | 48.5 | 50.1 | 52.8 | 50.3 | 53.2 | 53.9 | 50.5 | 52.9 | 54.4 | 51.1 | 54.4 | 56.1 |
| 6 | Max. | 57.1 | 56.0 | 56.4 | 57.4 | 56.3 | 56.9 | 55.5 | 55.8 | 54.4 | 54.5 | 54.4 | 54.4 | 55.8 | 55.0 | 54.5 |
| | Min. | 48.0 | 49.3 | 51.0 | 46.5 | 48.0 | 48.4 | 48.5 | 50.6 | 51.6 | 48.5 | 50.3 | 52.0 | 48.4 | 51.2 | 53.7 |
| 7 | Max. | 52.9 | 53.0 | 52.7 | 53.3 | 53.4 | 53.1 | 52.3 | 51.9 | 51.2 | 51.6 | 51.1 | 51.2 | 51.9 | 51.0 | 52.3 |
| | Min. | 45.4 | 47.5 | 49.2 | 45.0 | 46.5 | 48.5 | 46.3 | 48.5 | 49.5 | 47.5 | 48.1 | 49.5 | 46.1 | 48.9 | 51.8 |
| 8 | Max. | 46.2 | 46.9 | 47.4 | 46.0 | 46.3 | 47.0 | 45.8 | 46.9 | 47.1 | 46.0 | 47.0 | 47.6 | 45.6 | 47.0 | 50.1 |
| | Min. | 42.4 | 44.3 | 46.1 | 41.4 | 43.0 | 45.1 | 42.9 | 45.6 | 45.6 | 43.3 | 45.7 | 46.9 | 43.0 | 46.1 | 49.0 |
| 9 | Max. | 48.4 | 48.6 | 48.5 | 50.2 | 49.3 | 48.5 | 48.4 | 47.9 | 48.3 | 47.5 | 47.0 | 47.1 | 48.6 | 47.4 | 47.9 |
| | Min. | 39.3 | 40.8 | 42.8 | 38.1 | 39.5 | 41.7 | 39.5 | 42.3 | 44.0 | 39.9 | 41.9 | 44.2 | 39.4 | 45.1 | 47.0 |
| 11 | Max. | 64.2 | 59.4 | 57.8 | 66.2 | 62.3 | 60.0 | 61.2 | 57.4 | 53.4 | 59.7 | 56.4 | 53.9 | 58.0 | 52.1 | 49.5 |
| | Min. | 45.4 | 45.0 | 45.7 | 45.0 | 44.8 | 45.1 | 43 9 | 44.8 | 45.2 | 43.8 | 44.4 | 45.0 | 42.5 | 44.3 | 46.9 |
| 12 | Max. | 62.7 | 60.2 | 58.8 | 63.5 | 61.6 | 60.7 | 60.1 | 58.4 | 55.0 | 58.5 | 57.5 | 55.3 | 59.5 | 55.0 | 51.8 |
| | Min. | 48.0 | 48.1 | 49.3 | 47.3 | 48.4 | 48.8 | 47.0 | 48.3 | 49.0 | 47.0 | 47.9 | 49.0 | 45.5 | 47.7 | 49.7 |
| 13 | Max. | 56.6 | 57.9 | 56.9 | 59.0 | 58.5 | 57.8 | 58.0 | 56.6 | 54.3 | 58.0 | 56.5 | 55.1 | 57.7 | 54.2 | 52.9 |
| | Min. | 52.5 | 52.0 | 52.2 | 52.3 | 52.0 | 52.3 | 51.7 | 51.6 | 51.1 | 51.8 | 51.2 | 51.5 | 50.5 | 50.3 | 51.4 |
| 14 | Max. | 59.3 | 57.5 | 57.4 | 59.8 | 58.4 | 58.1 | 58.1 | 57.3 | 55.3 | 58.2 | 57.1 | 56.4 | 57.8 | 58.1 | 54.3 |
| | Min. | 52.9 | 52.8 | 53.1 | 52.5 | 52.5 | 52.9 | 52.5 | 52.7 | 52.4 | 52.7 | 52.7 | 53.0 | 51.8 | 51.9 | 53.0 |
| 15 | Max. | 64.9 | 60.9 | 59.8 | 65.8 | 62.5 | 61.1 | 62.0 | 59.6 | 57.0 | 61.0 | 58.2 | 57.4 | 62.0 | 58.5 | 55.4 |
| | Min. | 51.0 | 51.6 | 52.5 | 50.6 | 51.1 | 52.0 | 51.0 | 52.1 | 52.3 | 51.3 | 52.0 | 52.9 | 51.0 | 52.0 | 53.3 |
| 16 | Max. | 63.7 | 60.0 | 58.7 | 64.9 | 61.5 | 60.5 | 60.7 | 58.6 | 55.4 | 58.8 | 57.3 | 55.4 | 61.5 | 57.0 | 53.6 |
| | Min | 45 5 | 46.2 | 47.8 | 43.9 | 44.6 | 46.4 | 45.3 | 47.5 | 49.3 | 45.4 | 47.1 | 49.1 | 44.2 | 48.5 | 51.3 |
| 18 | Max. | 61.3 | 60.2 | 59.0 | 61.8 | 61.4 | 60.0 | 60.8 | 58.7 | 56.3 | 60.8 | 57.2 | 57.1 | 61.0 | 57.3 | 56.3 |
| | Min. | 56.3 | 56 5 | 55.6 | 56.1 | 56.8 | 56.3 | 56.7 | 55.5 | 54.0 | 56.8 | 55.3 | 54.7 | 56.5 | 54.5 | 54.4 |
| 19 | Max. | 61.8 | 60.0 | 58.0 | 62.3 | 61.2 | 59.0 | 60.9 | 58.0 | 56.2 | 60.5 | 57.9 | 57.0 | 61.5 | 57.2 | 55.8 |
| | Min. | 49.8 | 50 5 | 51.8 | 48.5 | 49.6 | 50.7 | 49.7 | 51.5 | 52.5 | 49.9 | 51.4 | 52.9 | 49.7 | 52.3 | 54.1 |
| 20 | Max. | 65.6 | 61.8 | 60.0 | 66.7 | 63.5 | 61.6 | 63.0 | 59.9 | 57.2 | 62.2 | 59.6 | 58.2 | 62.5 | 58.6 | 55.8 |
| | Min. | 49.8 | 50.0 | 51.1 | 48.6 | 49.0 | 50.2 | 49.2 | 50.8 | 51.5 | 49.6 | 50.6 | 52.0 | 48.5 | 51.0 | 53.5 |
| 21 | Max. | 63.2 | 58.7 | 57.9 | 64.5 | 60.8 | 59.1 | 59.9 | 57.7 | 55.4 | 59.0 | 56.8 | 55.9 | 57.9 | 55.5 | 54.0 |
| | Min. | 44.4 | 45.9 | 48.5 | 42.3 | 43 7 | 47.5 | 44.8 | 47.9 | 50.3 | 45.3 | 48.4 | 50.5 | 43.3 | 49.4 | 52.3 |
| 22 | Max. | 62.2 | 57.6 | 56.8 | 63.4 | 59.5 | 57.0 | 59.0 | 56.4 | 53.9 | 57.5 | 55.2 | 54.0 | 55.4 | 53.2 | 51.8 |
| | Min. | 42.1 | 43.5 | 44.9 | 40.3 | 41.3 | 43 8 | 41.7 | 45.4 | 47.2 | 42 0 | 45.9 | 47.9 | 40.6 | 46.0 | 49.7 |
| 23 | Max. | 58.8 | 54.8 | 54.4 | 59.5 | 56.0 | 55.3 | 55.8 | 54.0 | 52.4 | 54.4 | 52.8 | 52.4 | 53.5 | 52.2 | 51.0 |
| | Min. | 42.3 | 44.7 | 47.1 | 40.6 | 42.7 | 45.5 | 42 8 | 46.5 | 48.1 | 43.0 | 45 8 | 48.0 | 41.6 | 46.5 | 49.2 |
| 25 | Max. | 62.0 | 57.4 | 55.8 | 63.2 | 59.6 | 57.3 | 59.0 | 55.4 | 53.0 | 57.7 | 54.4 | 53.0 | 56.5 | 52.6 | 50.5 |
| | Min. | 45.0 | 45 6 | 47.0 | 44.0 | 41.8 | 46.2 | 44.2 | 46.1 | 46.8 | 44.2 | 45 3 | 46.6 | 43.8 | 45 7 | 48.4 |
| 26 | Max. | 58.6 | 55.0 | 53.0 | 59.7 | 56.8 | 53.7 | 56.2 | 52.5 | 51.1 | 54.9 | 51.5 | 51.2 | 53.5 | 50.5 | 49.8 |
| | Min. | 42.5 | 44.0 | 45.8 | 41.1 | 42.5 | 44.8 | 42.2 | 45.0 | 47.5 | 42.3 | 44.7 | 46.9 | 41.8 | 45.5 | 48.1 |
| 27 | Max. | 58.7 | 54.3 | 53.5 | 59.4 | 56.1 | 54.6 | 55.4 | 53.0 | 51.0 | 54.0 | 51.8 | 51.0 | 53.7 | 50.9 | 49.1 |
| | Min. | 43.6 | 44.5 | 45.5 | 42.5 | 43.4 | 44.8 | 43.2 | 44.9 | 45.5 | 43.3 | 44.4 | 45.1 | 41.9 | 44.3 | 47.2 |
| 28 | Max. | 61.0 | 56.2 | 55.2 | 61.9 | 57.8 | 56.8 | 57.4 | 54.9 | 52.1 | 56.3 | 53.9 | 52.3 | 55.3 | 52.1 | 49.7 |
| | Min. | 45.0 | 45.0 | 45.9 | 44.0 | 44.4 | 44.9 | 43.9 | 45.2 | 45.0 | 43.9 | 45.0 | 45.6 | 43.0 | 44.8 | 47.4 |
| 29 | Max. | 57.8 | 53.8 | 53.7 | 58.4 | 55.1 | 54.5 | 54.7 | 53.2 | 51.3 | 53.7 | 52.1 | 51.4 | 52.9 | 51.1 | 49.7 |
| | Min. | 44.8 | 45.6 | 46.8 | 43.8 | 45.4 | 46.2 | 44.5 | 46.0 | 47.0 | 44.6 | 45.6 | 46.9 | 43.6 | 46.1 | 47.5 |
| 30 | Max. | 59.6 | 55.1 | 54.1 | 60.8 | 56.9 | 55.5 | 56.7 | 53.8 | 51.4 | 55.3 | 52.8 | 51.5 | 54.4 | 51.4 | 49.2 |
| | Min. | 40.7 | 42.3 | 44.5 | 39.4 | 40.7 | 43.4 | 40.4 | 43.8 | 45.4 | 40.7 | 43.1 | 45.3 | 40.0 | 44.6 | 47.4 |
| Ave. | Max. | 59.58 | 56.98 | 56.19 | 60.40 | 58.18 | 57.15 | 57.57 | 55.82 | 53.86 | 56.71 | 55.00 | 54.17 | 56.73 | 54.18 | 52.85 |
| | Min. | 47.15 | 48.05 | 49.34 | 46.17 | 47.14 | 48.57 | 47.01 | 48.83 | 49.57 | 47.21 | 48.55 | 49.79 | 46.46 | 49.03 | 51.13 |
| | Range | 12.43 | 8.93 | 6.85 | 14.23 | 11.04 | 8.58 | 10.56 | 6.99 | 3.29 | 9.50 | 6.45 | 4.38 | 10.27 | 5.15 | 1.72 |

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TABLE 74.—MAXIMUM AND MINIMUM TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND, NOVEMBER, 1915.

| Date— Maximum, minimum. | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ |
| 1 Max.... | 58.6 | 55.9 | 55.2 | 59.1 | 56.7 | 56.5 | 55.5 | 54.7 | 52.4 | 54.7 | 53.9 | 52.9 | 54.6 | 52.4 | 50.7 |
| 1 Min.... | 45.8 | 47.5 | 49.4 | 45.1 | 46.5 | 49.0 | 45.8 | 48.5 | 49.5 | 46.0 | 48.1 | 49.6 | 45.0 | 48.9 | 49.5 |
| 2 Max.... | 47.6 | 47.5 | 47.9 | 47.5 | 47.5 | 47.9 | 46.7 | 47.2 | 48.1 | 46.5 | 46.7 | 48.1 | 45.8 | 48.5 | 50.0 |
| 2 Min.... | 43.8 | 45.5 | 47.5 | 43.0 | 45.0 | 47.0 | 43.8 | 46.8 | 47.5 | 43.8 | 45.4 | 47.4 | 43.8 | 46.7 | 48.5 |
| 3 Max.... | 50.0 | 47.1 | 46.8 | 50.5 | 48.0 | 47.3 | 47.7 | 46.4 | 45.4 | 46.8 | 45.3 | 45.4 | 44.5 | 44.4 | 45.5 |
| 3 Min.... | 34.0 | 36.7 | 39.5 | 32.7 | 35.0 | 38.2 | 34.9 | 39.0 | 41.5 | 34.6 | 38.0 | 41.0 | 36.1 | 41.0 | 44.2 |
| 4 Max.... | 54.5 | 50.8 | 50.0 | 55.2 | 52.0 | 51.0 | 51.5 | 49.6 | 47.6 | 50.6 | 48.9 | 47.8 | 49.8 | 47.6 | 46.2 |
| 4 Min.... | 42.0 | 42.4 | 43.2 | 41.5 | 42.1 | 43.0 | 41.5 | 42.6 | 43.1 | 41.7 | 42.4 | 43.2 | 41.1 | 42.3 | 44.6 |
| 5 Max.... | 45.8 | 45.2 | 45.5 | 45.8 | 45.2 | 45.5 | 44.6 | 44.9 | 44.7 | 44.6 | 44.2 | 44.9 | 44.0 | 44.4 | 45.5 |
| 5 Min.... | 40.4 | 41.4 | 42.6 | 39.4 | 40.5 | 42.0 | 40.1 | 42.1 | 43.2 | 40.5 | 41.7 | 43.3 | 39.2 | 42 4 | 44.8 |
| 6 Max.... | 48.9 | 46.8 | 46.0 | 49.3 | 47.2 | 46.9 | 46.0 | 45.4 | 43.9 | 45.5 | 45.1 | 44.3 | 44.9 | 42.8 | 43.0 |
| 6 Min.... | 34.6 | 36.7 | 38.7 | 33.4 | 35.3 | 37.5 | 34.8 | 37.9 | 39.8 | 35.0 | 37.5 | 39.6 | 35.4 | 39.2 | 41.9 |
| 8 Max.... | 63.0 | 58.4 | 54.3 | 64.3 | 60.8 | 57.0 | 60.3 | 55.1 | 52.7 | 59.7 | 54.5 | 53.3 | 58.6 | 53.0 | 49.7 |
| 8 Min.... | 51.2 | 50.0 | 49.0 | 51.5 | 50.6 | 49.8 | 49.8 | 48.5 | 46.9 | 50.1 | 48.5 | 47.5 | 49.2 | 46.6 | 46.0 |
| 9 Max.... | 52.9 | 49.5 | 49.1 | 53.8 | 51.1 | 50.2 | 51.2 | 49.2 | 48.2 | 50.2 | 48.1 | 48.0 | 49.3 | 47.5 | 47.1 |
| 9 Min.... | 38.6 | 41.1 | 43.8 | 37.5 | 39.7 | 42.8 | 39.1 | 42.9 | 44.9 | 39.4 | 42.4 | 44.8 | 39.4 | 44.3 | 45.9 |
| 10 Max.... | 43.8 | 44.2 | 44.4 | 43.8 | 44.3 | 44.7 | 43.3 | 43.9 | 43.3 | 43.4 | 43.6 | 43.6 | 42.4 | 42.1 | 44.2 |
| 10 Min.... | 46.3 | 38.0 | 40.1 | 34.8 | 36.5 | 39.0 | 36.3 | 39.5 | 41.4 | 36.4 | 38.7 | 41.0 | 35.9 | 40.3 | 43.1 |
| 11 Max.... | 55.9 | 54.2 | 52.7 | 56.0 | 54.9 | 53.5 | 54.5 | 52.3 | 49.4 | 54.6 | 52.4 | 50.5 | 53.8 | 49.6 | 47.1 |
| 11 Min.... | 48.5 | 46.9 | 45.8 | 48.5 | 47.0 | 46.2 | 46.8 | 45.5 | 44.3 | 47.1 | 45.3 | 45.0 | 45.6 | 43.8 | 44.4 |
| 12 Max.... | 49.0 | 47.2 | 46.0 | 49.8 | 48.5 | 47.1 | 48.5 | 46.7 | 46.4 | 48.6 | 46.8 | 46.6 | 48.0 | 46.1 | 47.4 |
| 12 Min.... | 39.3 | 41.6 | 44.3 | 37.8 | 40.0 | 43.1 | 39.7 | 43.8 | 45.4 | 40.1 | 43.5 | 45.7 | 40.0 | 44.9 | 45.9 |
| 13 Max.... | 45.6 | 43.5 | 43.4 | 43.3 | 44.5 | 43.6 | 45.0 | 43.6 | 43.2 | 44.8 | 43.3 | 43.6 | 43.1 | 42.5 | 43.6 |
| 13 Min.... | 34.6 | 36.8 | 38.8 | 33.5 | 35.4 | 37.7 | 35.5 | 38.7 | 40.5 | 35.4 | 38.0 | 40.5 | 36.8 | 40.2 | 42.5 |
| 15 Max.... | 35.4 | 36.1 | 37.4 | 35.4 | 35.5 | 36.8 | 34.9 | 37.0 | 38.3 | 36.0 | 36.8 | 38.1 | 36.1 | 38.0 | 40.6 |
| 15 Min.... | 34.0 | 35.8 | 36.9 | 33 3 | 34.8 | 36.4 | 34.3 | 36.5 | 37.5 | 34.2 | 36.4 | 37.5 | 35.3 | 37.3 | 39.7 |
| 16 Max.... | 34.3 | 35.2 | 36.1 | 33.5 | 34.5 | 35.7 | 34.0 | 35.4 | 36.4 | 34.4 | 35.5 | 36.4 | 34.2 | 36.4 | 38.8 |
| 16 Min.... | 32.9 | 34.3 | 35.5 | 32.2 | 33.5 | 34.8 | 33.0 | 34.9 | 36.0 | 32.7 | 34.4 | 35.9 | 33.7 | 35.8 | 38.3 |
| 17 Max.... | 42.3 | 39.3 | 39.8 | 42.1 | 39.7 | 40.0 | 39.5 | 39.4 | 38.6 | 42.5 | 39.8 | 39.6 | 38.4 | 38.5 | 37.6 |
| 17 Min.... | 33.8 | 34.8 | 35.7 | 33.4 | 34.3 | 35.4 | 33.8 | 35.4 | 36.0 | 34.3 | 35.3 | 36.3 | 33.8 | 35.2 | 37.5 |
| 18 Max.... | 39.9 | 39.7 | 39.5 | 40.1 | 39.7 | 39.8 | 39.2 | 39.0 | 38.2 | 40.1 | 39.5 | 39.0 | 37.7 | 36.8 | 37.6 |
| 18 Min.... | 33.9 | 35.0 | 36.0 | 33.3 | 34.3 | 35.5 | 33.9 | 35.6 | 36.4 | 34.1 | 35.4 | 36.5 | 34.0 | 35.3 | 37.2 |
| 19 Max.... | 41.4 | 41.3 | 41.1 | 41.3 | 41.5 | 41.4 | 40.7 | 40.4 | 40.0 | 41.2 | 40.6 | 40.8 | 39.8 | 39.5 | 39.8 |
| 19 Min.... | 38.0 | 38.8 | 39.8 | 37.7 | 38.7 | 39.9 | 37.9 | 39.3 | 39.6 | 38.6 | 39.6 | 40.2 | 37.9 | 38.8 | 39.1 |
| 20 Max.... | 38.5 | 38.7 | 38.8 | 38.7 | 38.8 | 38.9 | 38.0 | 38.1 | 38.2 | 38.8 | 38.5 | 38.5 | 37.6 | 37.6 | 38.8 |
| 20 Min.... | 35.4 | 36.7 | 37.7 | 35.0 | 36.2 | 37.5 | 35.4 | 37.2 | 37.8 | 36.0 | 37.3 | 37.9 | 35.5 | 37.2 | 38.5 |
| 22 Max.... | 32.9 | 34.0 | 34.8 | 32.6 | 33.7 | 34.8 | 33.3 | 34.7 | 35.4 | 33.5 | 34.5 | 35.5 | 33.7 | 35.0 | 37.6 |
| 22 Min.... | 32.8 | 33.9 | 34.6 | 32.5 | 33.6 | 34.6 | 33.3 | 34.6 | 35.2 | 33.4 | 34.3 | 35.3 | 33.5 | 34.8 | 36.7 |
| 23 Max.... | 32.6 | 33.5 | 34.2 | 32.2 | 33.2 | 34.0 | 32.7 | 34.0 | 34.6 | 33.2 | 33.9 | 34.7 | 33.3 | 34.3 | 36.2 |
| 23 Min.... | 32.3 | 33.4 | 34.0 | 32.1 | 33 0 | 34.0 | 32.5 | 33.9 | 34.4 | 33.0 | 33.9 | 34.6 | 33.2 | 34.2 | 36.0 |
| 24 Max.... | 35.8 | 36.5 | 36.7 | 35.2 | 36.0 | 36.5 | 34.8 | 35.5 | 35.0 | 35.4 | 34.2 | 35.7 | 33.2 | 34.0 | 35.7 |
| 24 Min.... | 33.3 | 34.0 | 34.5 | 32.8 | 33.5 | 34.4 | 32.9 | 34.0 | 34.3 | 33.3 | 35.7 | 34.7 | 33.0 | 33.9 | 35.5 |
| 26 Max.... | 50.8 | 48.5 | 47.4 | 51.9 | 49.5 | 48.8 | 48.4 | 46.2 | 44.5 | 48.8 | 47.2 | 45.6 | 47.5 | 44.0 | 41.6 |
| 26 Min.... | 43.9 | 43.7 | 43.5 | 43.8 | 43.8 | 43.8 | 43.0 | 42.7 | 41.5 | 43.5 | 43.0 | 42.5 | 42.3 | 40.5 | 39.9 |
| 27 Max.... | 46.5 | 45.4 | 44.9 | 47.0 | 45.8 | 45.0 | 44.2 | 44.4 | 44.0 | 44.4 | 44.5 | 44.9 | 44.3 | 43.5 | 43.2 |
| 27 Min.... | 41.5 | 43.2 | 44.3 | 40.8 | 42.5 | 44.1 | 41.6 | 43.4 | 43.0 | 41.7 | 43.2 | 43.6 | 42.0 | 42.6 | 42.7 |
| 29 Max.... | 34.9 | 36.4 | 37.6 | 34.3 | 35.5 | 36.9 | 35.2 | 37.1 | 38.0 | 35.5 | 37.1 | 38.5 | 36.5 | 38.1 | 40.2 |
| 29 Min.... | 34.3 | 35.8 | 36.9 | 33.8 | 34.8 | 36 1 | 34.7 | 36.4 | 37.1 | 35.2 | 36.5 | 37.5 | 35.6 | 37.3 | 39.3 |
| 30 Max.... | 33.9 | 35.0 | 36.0 | 33.5 | 34.6 | 35.7 | 34.0 | 35.6 | 36.3 | 34.7 | 35.8 | 36.7 | 34.9 | 36.4 | 38.4 |
| 30 Min.... | 33.7 | 34.7 | 35.7 | 33.3 | 34.3 | 35 3 | 33 8 | 35.3 | 35.8 | 34.4 | 35.4 | 36.3 | 34.3 | 35.9 | 37.7 |
| Ave. Max.. | 44.42 | 43.42 | 43.25 | 44.59 | 42.78 | 43.65 | 43.18 | 42.89 | 42.34 | 43.37 | 42.66 | 42.75 | 42.35 | 41.88 | 42.48 |
| Ave. Min.. | 38.20 | 39.00 | 40.15 | 37.16 | 38.29 | 39.73 | 37.78 | 39.64 | 40.35 | 38.03 | 39.44 | 40.54 | 37.91 | 39.82 | 41.42 |
| Ave. Range | 6.22 | 4.42 | 3.10 | 7.43 | 4.49 | 3.92 | 5.40 | 3.25 | 1.99 | 5.34 | 3.22 | 2.21 | 4.44 | 2.06 | 1.03 |

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Considering first tables 39 to 50 inclusive which contain the daily and monthly maximum and minimum and also the average monthly amplitude, of the different types of soil for the second year during which they were not covered with a layer of sand, it will be seen (1) that during the winter months when the soils were frozen the fluctuation, or the difference between the maximum and minimum, was practically negligible in all soils and at all three depths. With the exception of a few cases the monthly amplitude was of equal magnitude not only in all the soils but also in all the various depths, and it amounted as a rule to about 1°F. During a few days towards the middle of February, however, it amounted to several degrees at the upper 6-inch depth, in some of the soils.

(2) Immediately upon thawing in the spring the magnitude of fluctuation began to increase. It became greatest in the sand and gravel and slightly smaller in the loam and clay and least in peat. It continued to increase until June when it reached its maximum in all the soils at all three depths. As an average for this month it ran as follows for the 6, 12, and 18-inch depths respectively: gravel 14.63°, 5.73°, 2.52°; sand 14.67°, 5.51°, 1.37°; loam 11.53°, 1.71°, 0.37°; clay 11.67°, 2.59°, 0.58°; and, peat 4.19°, 0.36°, 0.39°F. At certain individual days during this month it ran as high as 20°F in the case of sand and gravel and only about 5°F in peat, at the 6-inch depth. From June on it began to decrease in every soil and at every depth and continued to diminish until the soils froze again.

(3) The soils which attained the lowest minimum temperature also attained the highest maximum and they arrange in the following descending order: sand or gravel, loam, clay, and peat. The difference, however, between the lowest minimum temperature of the different soils was not very large, the highest average variation for any month was only about 3°F. The difference, however, between the maximum of these soils was quite appreciable and especially betwen the sand or gravel and peat in which it amounted in some months, after complete thawing had taken place, to about 9°F. In other words the magnitude of the minimum temperature attained by the diverse classes of soils was about the same or very close, while that of the maximum varied somewhat and especially between the sand or gravel and peat.

The close equality of the minimum temperature in the diverse classes of soil, therefore, contradicts the common belief that the light soils become greatly colder or reach a far lower temperature during the night than the heavier soils and especially peat, while the rather marked difference in the maximum temperature goes to indicate that it is mainly this which is responsible for the variation in the average temperature observed in the various types of soil during the spring and summer months.

The data on the daily and monthly maximum and minimum and monthly range for the third year are contained in Tables 51 to 62 inclusive. It should be remembered that the soils during this year were covered with a thin layer of sand.

The order and magnitude of the fluctuation of the different soils during the third year agree with those of the second year just discussed, but the order and magnitude of the minimum and maximum disagree most markedly. Indeed, the latter were just reversed in the third year. The magnitude of the maximum became more equal in the various soils



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while the minimum varied appreciably, but the difference was not as great as was in the maximum in the preceding year, the greatest monthly variation being only about 5°F as against 10°F between the sand and peat.

Evidently, therefore, the cover of sand raised the maximum temperature, as well as it did the average, of the heavy types of soil and especially of peat, to the same degree as that of the light classes of soil. And by so doing it augmented their total intrinsic heat and their minimum temperature did not fall as low as that of the light soils. As already stated it accomplished this rise of temperature mainly by reducing the excess of water-evaporation.

The data of the fourth year during which the soils were not covered with sand and their temperature was measured at 2, 4, and 6-inch depths instead of 6, 12, and 18 as previously, are represented in Tables 63 to 74 inclusive. The results in these tables show that the magnitude and order of amplitude in the 6-inch depth were practically the same as in the second or corresponding year, when the soils remained uncovered, but in the 2 and 4-inch depths, they were of course somewhat different. The degree of fluctuation in these upper depths, and especially in the 2-inch, was higher but surprisingly approximately equal in the various soils. This means that the degree of amplitude in peat at the upper depths, was almost as great as that in sand and gravel.

The order and magnitude of the maximum and minimum at the 6-inch depth in all the soils were also the same as in the second year, but in the 2 and 4-inch depths they differed somewhat. The most important difference, however, is that the magnitude of the minimum of the peat at the 2-inch depth was equal to or slightly lower than that of sand or gravel, while at the lower depths it was always higher.

Temperature records taken at the upper ¼-inch depth by the mercury thermometer with small bulb as already described, also show that the peat at this depth attained in the morning, as a very general rule, a slightly lower minimum than the sand and gravel, at the same depth.

These unexpected large diurnal-nocturnal fluctuations and low minimum temperature of the peat at the surface or upper depths as compared with those of the light mineral soils, are undoubtedly due to the poor heat conductivity of the material. On account of the low heat transferring power of the peat, heat does not travel sufficiently rapidly from the lower depths to replenish some of that which is being lost at the surface and consequently it attains a low minimum, even though the temperature at a slightly lower depth is very high. For the same reason, during the insolation, the surface attains a high temperature. A low minimum and high maximum therefore give a high fluctuation at the surface.

From the above it would seem therefore that the factor of poor heat conductivity of peat predominates and exerts a slightly controlling influence on its temperature at or near its surface.

### THE DEGREE OF AMPLITUDE AT DIFFERENT DEPTHS AND THE LAW IT FOLLOWS.

As already seen the magnitude of the diurnal-nocturnal amplitude diminishes with depth. The remarkable fact, however, is that this decrease follows a mathematical law and indeed the geometric law, i. e.,

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the diurnal-nocturnal amplitude of oscillation of temperature decreases in geometric progression as the depth increases in arithmetric progression. The extraordinary closeness with which the actual fluctuation follows this law is shown by Table 75, which contains the observed and calculated fluctuation of the five different types of soil at four different depths. The observed amplitudes were obtained by taking records of the temperature every 20 minutes until the absolute maximum and minimum were attained at all different depths. The calculated values were secured by dividing the lowest observed fluctuation by the one preceding and then multiplying the other observed values by the ratio or constant thus obtained.

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TABLE 75.—DEGREE OF DIURNAL AMPLITUDE OF TEMPERATURE AT VARIOUS DEPTHS AND THE GEOMETRIC PROGRESSION LAW IT FOLLOWS.

| 1915. | Gravel. | | | | Sand. | | | | Loam. | | | | Clay. | | | | Peat. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0″ | 2″ | 4″ | 6″ | 0″ | 2″ | 4″ | 6″ | 0″ | 2″ | 4″ | 6″ | 0″ | 2″ | 4″ | 6″ | 0″ | 2″ | 4″ | 6″ |
| I. July 9-10: | | | | | | | | | | | | | | | | | | | | |
| Max. | 102.0 | 93.5 | 87.0 | 81.1 | 105 0 | 95.4 | 90.3 | 85.0 | 100 7 | 86.1 | 80.4 | 74.1 | 97.2 | 84.6 | 76.9 | 74.1 | 97.9 | 84.3 | 74.9 | 70.1 |
| Min. | 59.0 | 63.1 | 64.9 | 66.2 | 57.9 | 62.6 | 64.1 | 66.0 | 58.9 | 62.0 | 66.0 | 66.0 | 58.2 | 63.3 | 64.8 | 66.0 | 55.3 | 62.6 | 65.3 | 66.7 |
| Obs. diff. | 43.0 | 30.4 | 22.1 | 14.9 | 47.1 | 32.8 | 26.2 | 19.0 | 41.8 | 24.1 | 14.4 | 8.1 | 39.0 | 21.3 | 12.1 | 8.1 | 42.6 | 21.7 | 9.6 | 3.4 |
| Calc. diff. | ..... | 28.98 | 20.49 | 14.9 | ..... | 34.15 | 23.78 | 19.0 | ..... | 23.54 | 13.57 | 8.1 | ..... | 26.11 | 14.26 | 8.1 | ..... | 15.09 | 7.69 | 3.4 |
| II. August: | | | | | | | | | | | | | | | | | | | | |
| Max. | 97.6 | 88.9 | 83.9 | 79.8 | 100 3 | 91.4 | 87 1 | 82.9 | 94 0 | 82.6 | 77.8 | 73.1 | 97.9 | 85.8 | 80.0 | 76.3 | 100.0 | 86.5 | 77.8 | 73.4 |
| Min. | 58.4 | 62.7 | 64 6 | 66 4 | 56.0 | 61.5 | 63.3 | 65.6 | 57.5 | 61.8 | 65.3 | 65.7 | 58.0 | 63.5 | 65.7 | 67.0 | 53.9 | 62.5 | 65.9 | 68.1 |
| Obs. diff. | 39.2 | 26.2 | 19.3 | 13.4 | 44.3 | 29.9 | 23.8 | 17.3 | 36.5 | 20.8 | 12.5 | 7.4 | 39.9 | 22.3 | 14.3 | 9.3 | 46.1 | 24.0 | 11.9 | 5.3 |
| Calc. diff. | ..... | 27.22 | 18.19 | 13.4 | ..... | 32.2 | 21.73 | 17.3 | ..... | 21.61 | 12.31 | 7.4 | ..... | 25.95 | 14.50 | 9.3 | ..... | 20.53 | 10.73 | 5.3 |
| III. August 18-19: | | | | | | | | | | | | | | | | | | | | |
| Max. | 91.9 | 84.0 | 79.3 | 75.5 | 94.0 | 86.9 | 82.8 | 78.8 | 90.0 | 78.9 | 74.5 | 70.1 | 87.6 | 79.0 | 74.1 | 71.1 | 91.9 | 79.1 | 71.9 | 68.2 |
| Min. | 51.0 | 55.8 | 58.4 | 61.1 | 48.7 | 54.0 | 56.6 | 59.6 | 50.0 | 55.3 | 60.3 | 61.6 | 50.2 | 56.9 | 59.7 | 62.0 | 45.0 | 55.1 | 60.5 | 63.8 |
| Observ. diff. | 40.9 | 28.2 | 20 9 | 14.4 | 45.3 | 32.9 | 26.2 | 19.2 | 40.0 | 23.6 | 14.2 | 8.5 | 37.4 | 22.1 | 14.4 | 9.1 | 46.9 | 24.0 | 11.4 | 4.4 |
| Calc. diff. | ..... | 28.21 | 19.45 | 14.4 | ..... | 33.20 | 24.11 | 19.2 | ..... | 23.94 | 14.13 | 8.5 | ..... | 23.64 | 13.97 | 9.1 | ..... | 18.10 | 9.26 | 4.4 |
| IV. August 26-27: | | | | | | | | | | | | | | | | | | | | |
| Max. | 86.9 | 79.4 | 75.4 | 71.8 | 88.5 | 80.9 | 77.6 | 74.1 | 86.2 | 75.9 | 71.3 | 67.5 | 84.9 | 76.1 | 71.3 | 68.7 | 89.2 | 76.9 | 69.8 | 67.2 |
| Min. | 44.5 | 50.8 | 53.8 | 56.9 | 41.9 | 48.7 | 51.5 | 55.0 | 42.7 | 50.4 | 55.7 | 57.8 | 43.4 | 51.4 | 55.1 | 58.0 | 37.3 | 49.7 | 56.3 | 60.8 |
| Obs. diff. | 42.4 | 28.6 | 21.6 | 14.9 | 46.6 | 32.2 | 26 1 | 19.1 | 43.5 | 25.5 | 15.6 | 9.7 | 41.5 | 24.7 | 16.2 | 10.7 | 51.9 | 27.2 | 13.5 | 6.4 |
| Calc. diff. | ..... | 29.24 | 19.73 | 14.9 | ..... | 34.10 | 23.56 | 19.1 | ..... | 27.05 | 15.85 | 9.7 | ..... | 27.41 | 16.31 | 10.7 | ..... | 24.60 | 12.89 | 6.4 |
| V. September 2-3: | | | | | | | | | | | | | | | | | | | | |
| Max. | 96.2 | 85.2 | 80.2 | 75.7 | 101.0 | 84.7 | 81.0 | 77.2 | 94.7 | 80.9 | 75.0 | 70.1 | 93.2 | 81.1 | 75.5 | 71.4 | 97.2 | 82.4 | 73.5 | 68.7 |
| Min. | 56.7 | 60.4 | 62.0 | 63.4 | 54.0 | 59.7 | 61.1 | 63.0 | 55.7 | 59.6 | 62.5 | 62.6 | 55.7 | 60.2 | 62.0 | 63.3 | 53.0 | 59.6 | 62.6 | 64.6 |
| Observ. diff. | 39.5 | 24.8 | 18 2 | 12.3 | 47.0 | 25.0 | 19.9 | 14.2 | 39.0 | 21.3 | 12.5 | 7.5 | 37.5 | 20.9 | 13.5 | 8.1 | 44.2 | 22.8 | 10.9 | 4.1 |
| Calcul. diff. | ..... | 26.70 | 16.76 | 12.3 | ..... | 33.54 | 17.84 | 14.2 | ..... | 23.40 | 12.78 | 7.5 | ..... | 22.50 | 12.42 | 8.1 | ..... | 16.62 | 8.57 | 4.1 |
| VI. October 22-23: | | | | | | | | | | | | | | | | | | | | |
| Max. | 70.0 | 63.0 | 59.8 | 57.1 | 69.6 | 64.3 | 61.7 | 58.9 | 69.7 | 60.8 | 56.8 | 53.9 | 66.0 | 59.0 | 55.8 | 54.0 | 67.8 | 57.8 | 53.2 | 52.5 |
| Min. | 38.0 | 42.3 | 44.6 | 46 6 | 36.3 | 40.5 | 42.7 | 45.3 | 37.2 | 42.3 | 46.1 | 47.4 | 37.0 | 43.0 | 45.3 | 47.4 | 33.0 | 41.5 | 45.5 | 49.2 |
| Observ. diff. | 32.0 | 20.7 | 15.2 | 10.5 | 33.3 | 23.8 | 19.0 | 13.6 | 32.5 | 18.0 | 10.7 | 6.5 | 29.0 | 16.0 | 10.5 | 6.6 | 34 8 | 16.3 | 7.7 | 3.3 |
| Calc. diff. | ..... | 22.10 | 14.30 | 10.5 | ..... | 23.84 | 17.04 | 13.6 | ..... | 19.74 | 10.93 | 6.5 | ..... | 18.23 | 10.06 | 6.6 | ..... | 14.91 | 6.99 | 3.3 |

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It is readily seen from the above table, therefore, that the calculated and observed diurnal amplitudes are remarkably close in all the diverse types of soil and consequently the law is valid.

Since the actual diurnal-nocturnal fluctuations follow the geometric progression law they are expressable then by the formula $A=FR^{n-1}$, where A is the amplitude, F the first fluctuation, R the ratio of any amplitude (except the first) to the preceding one, and n the number of the amplitude. According to this equation, therefore, if the amplitude is known at two different depths it can be calculated at any other depth.

### THE RELATION BETWEEN THE MINIMUM TEMPERATURE OF THE SOIL AT THE SURFACE AND THAT OF THE AIR ABOVE.

On account of the absorption of the solar energy the temperature of the soil immedately at the surface at the time that it reaches its maximum is many degrees higher than that of the air above, amounting sometimes to about 30°F. In certain sections of the world this difference must be far greater.

During the night, however, i. e., when the minimum temperature is attained at the surface soil, no such great difference exists. Indeed, both the air and surface soil reach practically equal minimum temperature, as the data in Table 76 show. These data were obtained by placing on the surface soil and about four feet in the air, minimum thermometers of the standard type, and taking records every morning for six months. During the months of June, July, August, and September the thermometers were exposed to the sky, but during September, October and November they were covered with wooden boxes with perforations all around them to allow free circulation of air and consequently the rapid attainment of the actual air temperature. For lack of space only the averages for the various months are presented here.

TABLE 76.—MONTHLY AVERAGE MINIMUM TEMPERATURE OF THE SOIL AT THE SURFACE AND THAT OF THE AIR ABOVE.

| | June. | July. | August. | September. | October. | November. |
|---|---|---|---|---|---|---|
| Surface soil | 49.36 | 58.03 | 53.88 | 52.04 | 39.74 | 33.48 |
| Air | 47.90 | 56.42 | 52.34 | 50.83 | 38.92 | 31.35 |

It is to be noted, therefore, that even during the night the surface soil had a higher temperature than the air above, but the difference is comparatively small, amounting to less than 2°F. In many individual nights the air temperature would be that many degrees warmer.

The above results on the soil surface temperature were obtained on a sandy loam. Now it has already been seen that the mineral soils maintain a slightly higher temperature during the night than peat. Hence peat would always have equal or slightly lower temperature at the surface than the air above.

It is an interesting fact that during the night, say at the time that the minimum temperature is attained at the surface soil, the temperature of the air increases with the elevation up to a certain height and

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the soil temperature increases with the depth, while during the day the reverse is true.

### SEASONAL AND YEARLY AVERAGE TEMPERATURE.

From the theoretical as well as from the practical standpoint it is very interesting and important to know what is the seasonal and yearly average temperature. These data of the different types of soil at the various depths for the three years are presented in Tables 77, 78 and 79 inclusive.

TABLE 77.—MONTHLY, SEASONAL AND YEARLY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND.

| 1912-1913 | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | | Air |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season. | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | |
| Winter: | | | | | | | | | | | | | | | | |
| Dec.... | 33.45 | 34 71 | 36.81 | 33.53 | 35.03 | 37.32 | 33.45 | 35.77 | 37.60 | 33.65 | 35.75 | 37.12 | 33.86 | 35.73 | 38.36 | 31.0 |
| Jan.... | 32.39 | 33 38 | 34.82 | 32 11 | 33.41 | 35.06 | 31.64 | 33.66 | 35.18 | 32.19 | 33.82 | 34.94 | 31.76 | 33.36 | 35.78 | 26.2 |
| Feb.... | 28.40 | 29 70 | 31 67 | 28.01 | 29.96 | 32.09 | 28.23 | 30 94 | 32.53 | 28.59 | 30.77 | 31.99 | 27.61 | 30.77 | 33.31 | 20.0 |
| **Ave....** | **31.41** | **32.60** | **34.43** | **31.22** | **32.80** | **34.82** | **31.11** | **33.46** | **35.13** | **31.48** | **33.45** | **34.68** | **31.08** | **33.29** | **35.82** | **25.73** |
| Spring: | | | | | | | | | | | | | | | | |
| Mar... | 34 16 | 33 81 | 33.79 | 33.88 | 33.60 | 33.81 | 32.10 | 31.56 | 32.46 | 32.95 | 32.25 | 32.57 | 31.33 | 31.33 | 32.91 | 31.0 |
| Apr.... | 48.84 | 45 83 | 44 36 | 48 49 | 45.31 | 44.13 | 46.38 | 43.83 | 42 56 | 46 21 | 44.11 | 43.22 | 39.76 | 37.06 | 39.11 | 45.9 |
| May... | 61 01 | 57.80 | 56 35 | 60.75 | 57.43 | 55 65 | 59.36 | 56 61 | 54.36 | 58.51 | 56 22 | 55.03 | 58.03 | 55.61 | 54.20 | 56.2 |
| **Ave....** | **48.00** | **45.81** | **44.83** | **47.68** | **45.45** | **44.54** | **45.95** | **44.00** | **43.13** | **45.59** | **44.19** | **43.61** | **43.04** | **41.33** | **42.07** | **44.37** |
| Summer: | | | | | | | | | | | | | | | | |
| Jun.... | 75 72 | 71 29 | 69.32 | 74.30 | 70.13 | 67.34 | 73 80 | 69.78 | 65.88 | 72.74 | 68.82 | 66.46 | 70.54 | 66.85 | 64.58 | 67.6 |
| July... | 78.73 | 75 77 | 74.74 | 77.23 | 74.79 | 73.34 | 77.89 | 75.25 | 72.55 | 76.38 | 74.11 | 72.79 | 75.34 | 73.75 | 71.96 | 70.8 |
| Aug.... | 76.19 | 73.70 | 73 23 | 75.64 | 73.43 | 72.53 | 75.12 | 73.50 | 71.87 | 73.89 | 72.61 | 72 02 | 74.24 | 73.54 | 72.45 | 69.4 |
| **Ave....** | **76.88** | **73.59** | **72.43** | **75.72** | **72.78** | **71.07** | **75.60** | **72.84** | **70.10** | **74.34** | **71.85** | **70.42** | **73.37** | **71.38** | **69.66** | **69.27** |
| Autumn: | | | | | | | | | | | | | | | | |
| Sep.... | 66.59 | 65.35 | 65.45 | 66 09 | 65 09 | 65.34 | 65.50 | 65.34 | 61.96 | 65.22 | 64.56 | 65.12 | 65.27 | 65 63 | 65.69 | 61.0 |
| Oct.... | 53.24 | 53.66 | 54.46 | 52.75 | 53.58 | 55.07 | 52 54 | 54.05 | 55.07 | 52.78 | 52.79 | 55.11 | 53.03 | 54.88 | 56.37 | 50.2 |
| Nov... | 42.02 | 42.67 | 43 71 | 41.97 | 42.96 | 44.42 | 41.90 | 43.18 | 44 33 | 42.29 | 42.60 | 44 42 | 41.95 | 43.42 | 45.45 | 41.7 |
| **Ave....** | **53.95** | **53.89** | **54.54** | **53.60** | **53.88** | **54.94** | **53.01** | **54.19** | **54.79** | **53.43** | **53.32** | **54.88** | **53.42** | **54.64** | **56.84** | **50.97** |
| **Yr. ave.** | **52.56** | **51.48** | **51.53** | **51.22** | **51.23** | **51.35** | **51.42** | **51.12** | **50.79** | **51.29** | **50.70** | **50.90** | **50.23** | **50.16** | **50.85** | **47.58** |

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TABLE 73.—MONTHLY, SEASONAL, AND YEARLY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND.

| 1913–14 | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season. | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | |
| Winter: | | | | | | | | | | | | | | | | |
| Dec.... | 36.22 | 37.91 | 39.05 | 35.73 | 38.13 | 40.41 | 36.25 | 38.81 | 40.61 | 36.59 | 38.62 | 40.40 | 37.09 | 39.74 | 42.03 | 31.8 |
| Jan.... | 33.70 | 34.81 | 35.48 | 33.39 | 34.85 | 36.38 | 33.05 | 34.80 | 36.21 | 34.00 | 35.14 | 36.30 | 33.10 | 34.76 | 36.90 | 27.0 |
| Feb.... | 33.44 | 34.53 | 35.18 | 32.76 | 34.36 | 35.90 | 33.12 | 34.73 | 35.89 | 33.73 | 34.89 | 35.91 | 33.42 | 34.74 | 36.56 | 12.7 |
| Ave.... | 34.45 | 35.75 | 36.57 | 33.96 | 35.78 | 37.56 | 34.14 | 36.11 | 37.57 | 34.77 | 36.22 | 37.54 | 34.54 | 36.41 | 38.50 | 23.83 |
| Spring: | | | | | | | | | | | | | | | | |
| Mar.... | 35.99 | 36.18 | 36.33 | 35.58 | 35.97 | 36.55 | 35.33 | 35.94 | 36.25 | 35.97 | 36.02 | 36.56 | 33.59 | 34.46 | 36.03 | 31.1 |
| Apr.... | 46.80 | 45.35 | 44.73 | 47.16 | 45.34 | 44.34 | 45.84 | 44.64 | 43.23 | 45.74 | 44.44 | 43.74 | 44.79 | 43.18 | 42.82 | 44.7 |
| May... | 59.87 | 57.47 | 56.48 | 60.29 | 57.31 | 55.64 | 59.14 | 56.93 | 54.40 | 59.44 | 56.73 | 55.46 | 59.16 | 56.41 | 54.82 | 58.6 |
| Ave.... | 47.55 | 46.33 | 45.85 | 47.68 | 46.21 | 45.51 | 46.77 | 45.84 | 44.63 | 47.05 | 45.76 | 45.25 | 45.85 | 44.68 | 44.56 | 44.80 |
| Summer: | | | | | | | | | | | | | | | | |
| Jun.... | 71.71 | 69.36 | 68.35 | 71.56 | 68.79 | 67.12 | 71.69 | 69.00 | 65.97 | 71.40 | 68.42 | 67.18 | 72.48 | 69.57 | 67.24 | 66.0 |
| July... | 75.92 | 74.08 | 72.62 | 75.24 | 73.30 | 71.53 | 75.80 | 73.27 | 70.15 | 75.31 | 72.25 | 71.26 | 76.93 | 74.06 | 71.74 | 71.0 |
| Aug.... | 73.39 | 71.99 | 71.77 | 72.69 | 71.69 | 71.09 | 73.35 | 72.20 | 70.37 | 72.88 | 71.20 | 71.16 | 74.02 | 73.15 | 72.14 | 68.9 |
| Ave.... | 73.67 | 71.81 | 70.93 | 73.16 | 71.26 | 69.91 | 73.61 | 71.49 | 68.83 | 73.20 | 70.62 | 69.87 | 74.44 | 72.26 | 70.37 | 68.63 |
| Autumn: | | | | | | | | | | | | | | | | |
| Sept. | 63.91 | 63.58 | 63.89 | 63.30 | 63.42 | 64.01 | 63.79 | 64.05 | 63.47 | 63.62 | 63.55 | 64.04 | 64.35 | 64.84 | 65.03 | 60.3 |
| Oct.... | 55.86 | 56.16 | 56.97 | 55.54 | 56.15 | 57.57 | 55.56 | 56.71 | 57.45 | 55.79 | 56.45 | 57.51 | 56.33 | 57.87 | 59.03 | 54.6 |
| Nov... | 39.26 | 40.97 | 42.14 | 38.22 | 41.50 | 43.46 | 39.49 | 41.87 | 43.61 | 39.93 | 41.72 | 43.65 | 39.84 | 42.92 | 45.55 | 37.6 |
| Ave.... | 53.01 | 53.57 | 54.33 | 52.35 | 53.69 | 55.01 | 52.95 | 54.21 | 54.84 | 53.11 | 53.91 | 55.07 | 53.51 | 55.21 | 56.54 | 50.83 |
| Yr. ave... | 52.17 | 51.87 | 51.82 | 51.47 | 51.74 | 52.00 | 51.87 | 51.92 | 51.47 | 52.04 | 51.63 | 51.94 | 52.09 | 52.14 | 52.49 | 47.02 |

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TABLE 79.—MONTHLY, SEASONAL, AND YEARLY AVERAGE TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND.

| 1914-15 | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | 2″ | 4″ | 6″ | |
| Winter: | | | | | | | | | | | | | | | | |
| Dec.... | 32.28 | 33.03 | 33.73 | 30.23 | 31.81 | 32.77 | 32.54 | 33.56 | 33.83 | 32.29 | 32.96 | 33.72 | 33.30 | 34.01 | 35.35 | 21.6 |
| Jan.... | 31.81 | 32.30 | 32.65 | 30.59 | 31.28 | 31.99 | 31.28 | 32.05 | 32.02 | 31.87 | 32.03 | 32.46 | 32.05 | 31.93 | 32.58 | 20.4 |
| Feb.... | 32.21 | 32.74 | 32.96 | 32.19 | 32.73 | 33.13 | 31.49 | 32.13 | 31.95 | 32.11 | 32.31 | 32.73 | 31.93 | 31.74 | 32.40 | 29.4 |
| **Ave....** | **32.10** | **32.69** | **33.11** | **31.00** | **31.94** | **32.62** | **31.77** | **32.58** | **32.60** | **32.09** | **32.43** | **32.97** | **32.43** | **32.57** | **33.44** | **23.80** |
| Spring: | | | | | | | | | | | | | | | | |
| Mar.... | 34.33 | 34.37 | 34.28 | 34.34 | 34.48 | 34.64 | 33.27 | 33.89 | 33.47 | 33.86 | 33.74 | 33.88 | 31.80 | 31.59 | 32.23 | 30.1 |
| Apr.... | 56.16 | 54.82 | 52.95 | 56.22 | 54.36 | 53.60 | 55.25 | 52.95 | 50.10 | 54.41 | 52.03 | 50.69 | 49.90 | 46.59 | 45.80 | 51.6 |
| May.... | 58.54 | 57.77 | 56.76 | 58.74 | 58.11 | 56.78 | 56.96 | 56.37 | 54.34 | 57.39 | 55.31 | 54.92 | 56.69 | 54.97 | 54.48 | 51.5 |
| **Ave....** | **49.68** | **48.99** | **48.00** | **49.77** | **48.98** | **48.34** | **48.49** | **47.74** | **45.97** | **48.55** | **47.03** | **46.50** | **46.15** | **44.38** | **44.17** | **44.40** |
| Summer: | | | | | | | | | | | | | | | | |
| Jun.... | 69.78 | 67.92 | 66.79 | 69.98 | 68.55 | 67.22 | 67.86 | 66.42 | 63.79 | 67.84 | 65.46 | 64.45 | 67.53 | 64.65 | 63.65 | 61.0 |
| July.... | 75.70 | 74.18 | 72.70 | 76.18 | 74.96 | 73.69 | 73.41 | 72.82 | 70.12 | 74.39 | 71.55 | 71.04 | 74.20 | 71.51 | 70.16 | 67.9 |
| Aug.... | 70.50 | 69.45 | 68.58 | 70.80 | 70.00 | 69.26 | 68.54 | 68.06 | 66.28 | 69.44 | 68.17 | 67.38 | 69.42 | 67.50 | 67.28 | 63.4 |
| **Ave....** | **71.99** | **70.52** | **69.36** | **72.32** | **71.17** | **70.06** | **69.94** | **69.10** | **66.73** | **70.56** | **68.39** | **67.62** | **70.38** | **67.89** | **67.03** | **64.10** |
| Autumn | | | | | | | | | | | | | | | | |
| Sept.... | 67.67 | 66.74 | 65.78 | 68.23 | 67.41 | 66.73 | 67.22 | 65.90 | 63.94 | 66.67 | 65.47 | 64.58 | 66.88 | 64.74 | 64.47 | 63.2 |
| Oct.... | 53.66 | 53.65 | 53.16 | 54.13 | 53.97 | 53.61 | 53.38 | 52.78 | 51.58 | 52.88 | 52.34 | 51.97 | 52.94 | 51.46 | 51.85 | 51.1 |
| Nov.... | 41.37 | 41.67 | 41.87 | 41.14 | 41.52 | 41.91 | 40.95 | 41.45 | 41.25 | 41.07 | 41.18 | 41.58 | 40.50 | 40.73 | 41.94 | 39.8 |
| **Ave....** | **54.23** | **54.02** | **53.60** | **54.50** | **54.30** | **54.08** | **53.85** | **53.38** | **52.26** | **53.54** | **53.00** | **52.71** | **53.44** | **52.31** | **52.75** | **51.37** |
| **Yr. ave...** | **52.00** | **51.56** | **51.02** | **51.90** | **51.60** | **51.28** | **51.01** | **50.70** | **49.39** | **51.17** | **50.21** | **49.95** | **50.60** | **49.29** | **49.35** | **45.92** |

An examination of the foregoing tables shows the following most important facts: (1) In all three years the highest seasonal average temperature occurred in the summer, a slightly lower in the spring and autumn and the lowest in the winter. The fall temperature was slightly higher than that of the spring. (2) In all the four seasons there was a greater or less gradient of temperature at the various depths. During the seasons of spring, summer and fall this gradient diminished with increase in depth but in the winter the reverse was true. (3) The magnitude of the yearly average temperature was practically the same for all types of soil and equal at all three depths, i. e., the upper 18-inch layer of the different types of soil had practically the same magnitude of yearly average temperature. (4) The average air temperature was more or less lower than that of all the soils at any depth in all four seasons.

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### SEASONAL AND YEARLY MAXIMUM, MINIMUM, AND AMPLITUDE OF TEMPERATURE.

Of equal interest and importance as the average seasonal and yearly average temperature, is the seasonal, yearly maximum, minimum, and amplitude of temperature of the various soils. These data are contained in Tables 80, 81 and 82 for the three years, respectively.

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TABLE 80.—MONTHLY, SEASONAL AND YEARLY MAXIMUM, MINIMUM AND AMPLITUDE OF TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND.

| 1912-1913. | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | |
| Winter: | | | | | | | | | | | | | | | | | |
| Dec. | Max. | 33.98 | 35.08 | 37.08 | 34.15 | 35.42 | 37.58 | 33.80 | 36.05 | 37.89 | 34.06 | 36.02 | 37.34 | 34.12 | 35.93 | 38.54 | 38.1 |
| | Min. | 32.98 | 34.34 | 36.55 | 32.98 | 34.65 | 37.07 | 33.12 | 35.51 | 37.48 | 33.27 | 35.49 | 36.90 | 33.58 | 35.51 | 38.18 | 23 9 |
| | Diff. | 1.00 | 0.74 | 0.53 | 1.17 | 0.77 | 0.51 | 0.68 | 0.54 | 0.41 | 0.79 | 0.53 | 0.44 | 0.54 | 0.42 | 0.36 | 14.2 |
| Jan. | Max. | 32.58 | 33.56 | 35.00 | 32.30 | 33.56 | 35.19 | 31.80 | 33.81 | 35.33 | 32.34 | 33.98 | 35.08 | 31.93 | 33.53 | 35.93 | 34.2 |
| | Min. | 32.20 | 33.20 | 34.64 | 31.94 | 33.24 | 34.89 | 31.47 | 33.49 | 35.03 | 32.01 | 33.64 | 34.78 | 31.62 | 33.20 | 35.62 | 18.2 |
| | Diff. | 0.38 | 0.36 | 0.36 | 0.36 | 0.32 | 0.30 | 0.33 | 0.32 | 0.30 | 0.33 | 0.34 | 0.30 | 0.31 | 0.33 | 0.31 | 16.0 |
| Feb. | Feb. | 29.35 | 30.13 | 31.88 | 28.97 | 30.36 | 32.28 | 28.75 | 31.13 | 32.76 | 29.03 | 31.01 | 32.20 | 28.48 | 30.99 | 33.51 | 27.9 |
| | Min. | 27.77 | 29.30 | 31.50 | 26.59 | 29.58 | 31.90 | 27.84 | 30.77 | 32.32 | 28.14 | 30.58 | 31.77 | 26.98 | 30.56 | 33.09 | 12.1 |
| | Diff. | 1.58 | 0.83 | 0.38 | 2.38 | 0.78 | 0.38 | 0.91 | 0.36 | 0.44 | 0.89 | 0.43 | 0.43 | 1.50 | 0.43 | 0.42 | 15.8 |
| Seasonal. | Max. | 31.97 | 32.92 | 34.65 | 31.81 | 33.11 | 35.02 | 31.45 | 33.66 | 35.33 | 31.81 | 33.67 | 34.67 | 31.51 | 33.48 | 35.99 | 33.40 |
| | Min. | 30.98 | 32.28 | 34.23 | 30.50 | 32.49 | 34.62 | 30.81 | 33.26 | 34.94 | 31.14 | 33.24 | 34.48 | 30.73 | 33.09 | 35.63 | 18.07 |
| | Diff. | 0.99 | 0.64 | 0.42 | 1.31 | 0.62 | 0.40 | 0.64 | 0.40 | 0.39 | 0.67 | 0.43 | 0.39 | 0.78 | 0.39 | 0.36 | 15.33 |
| Spring: | | | | | | | | | | | | | | | | | |
| Mar. | Max. | 34.98 | 34.30 | 34.06 | 34.81 | 34.08 | 34.13 | 32.61 | 31.73 | 32.65 | 33.48 | 32.45 | 32.77 | 31.54 | 31.52 | 33.08 | 41.6 |
| | Min. | 33.29 | 33.41 | 33.52 | 32.91 | 33.17 | 33.54 | 31.66 | 31.40 | 32.26 | 32.49 | 32.05 | 32.39 | 31.14 | 31.13 | 32.74 | 20.5 |
| | Diff. | 1.69 | 0.89 | 0.54 | 1.90 | 0.91 | 0.59 | 0.95 | 0.33 | 0.39 | 0.99 | 0.40 | 0.38 | 0.40 | 0.39 | 0.34 | 21.1 |
| Apr. | Max. | 53.28 | 47.52 | 44.80 | 53.31 | 46.92 | 44.56 | 50.16 | 44.28 | 42.82 | 49.42 | 44.55 | 43.52 | 40.70 | 37.35 | 39.43 | 56.6 |
| | Min. | 43.39 | 44.77 | 43.98 | 42.86 | 44.27 | 43.75 | 42.93 | 43.44 | 42.30 | 43.60 | 43.73 | 42.95 | 38.78 | 36.80 | 38.82 | 35.2 |
| | Diff. | 9.89 | 2.75 | 0.82 | 10.45 | 2.65 | 0.81 | 7.23 | 0.84 | 0.52 | 5.82 | 0.82 | 0.57 | 1.92 | 0.55 | 0.61 | 21.4 |
| May | Max. | 66.01 | 60.02 | 57.17 | 66.32 | 59.77 | 56.26 | 63.53 | 57.22 | 54.60 | 62.31 | 57.00 | 55.31 | 59.73 | 55.85 | 54.34 | 67.2 |
| | Min. | 54.88 | 56.35 | 55.72 | 53.97 | 55.83 | 55.12 | 55.41 | 56.10 | 54.15 | 54.91 | 55.66 | 54.79 | 56.92 | 55.38 | 54.08 | 45.1 |
| | Diff. | 11.13 | 3.67 | 1.45 | 12.35 | 3.94 | 1.14 | 8.12 | 1.12 | 0.45 | 7.40 | 1.34 | 0.52 | 2.81 | 0.47 | 0.26 | 22.1 |
| Seasonal. | Max. | 51.42 | 47.28 | 45.34 | 51.48 | 46.92 | 44.99 | 48.77 | 44.41 | 43.36 | 48.40 | 44.67 | 43.87 | 43.99 | 41.57 | 42.28 | 55.13 |
| | Min. | 43.85 | 44.84 | 44.41 | 43.25 | 44.42 | 44.14 | 43.33 | 43.65 | 42.90 | 43.67 | 43.81 | 43.38 | 42.28 | 41.10 | 41.88 | 33.60 |
| | Diff. | 7.57 | 2.44 | 0.93 | 8.23 | 2.50 | 0.84 | 5.44 | 0.76 | 0.46 | 4.73 | 0.86 | 0.49 | 1.71 | 0.47 | 0.40 | 21.53 |
| Summer: | | | | | | | | | | | | | | | | | |
| June. | Max. | 82.17 | 74.71 | 70.68 | 80.80 | 73.54 | 67.96 | 80.15 | 70.60 | 66.07 | 78.59 | 70.24 | 66.78 | 73.24 | 67.03 | 64.77 | 81.5 |
| | Min. | 67.54 | 68.98 | 68.16 | 66.13 | 68.03 | 66.59 | 68.62 | 68.89 | 65.70 | 66.92 | 67.65 | 66.20 | 60.05 | 66.67 | 64.38 | 53.7 |
| | Diff. | 14.63 | 5.73 | 2.52 | 14.67 | 5.51 | 1.37 | 11.53 | 1.71 | 0.37 | 11.67 | 2.59 | 0.58 | 4.19 | 0.36 | 0.39 | 27.8 |
| July. | Max. | 85.15 | 78.77 | 75.83 | 83.65 | 77.85 | 73.87 | 83.12 | 75.85 | 72.80 | 81.55 | 75.09 | 73.14 | 77.85 | 73.99 | 72.09 | 83.0 |
| | Min. | 72.08 | 74.02 | 73.74 | 70.10 | 73.06 | 72.68 | 73.29 | 74.51 | 72.29 | 71.69 | 73.24 | 72.50 | 73.98 | 73.50 | 71.82 | 58.5 |
| | Diff. | 13.07 | 4.75 | 2.09 | 13.55 | 4.79 | 1.19 | 9.83 | 1.34 | 0.51 | 9.86 | 1.85 | 0.64 | 3.87 | 0.49 | 0.27 | 24.5 |
| Aug. | Max. | 82.05 | 76.41 | 74.07 | 82.16 | 76.46 | 73.08 | 80.20 | 74.18 | 72.22 | 79.12 | 73.41 | 72.41 | 76.65 | 73.87 | 72.62 | 81.1 |
| | Min. | 69.55 | 72.13 | 72.38 | 67.72 | 71.67 | 71.90 | 70.92 | 72.83 | 71.53 | 69.95 | 71.81 | 71.68 | 72.82 | 73.22 | 72.27 | 57.6 |
| | Diff. | 12.50 | 4.28 | 1.69 | 14.44 | 4.79 | 1.18 | 9.28 | 1.35 | 0.69 | 9.17 | 1.60 | 0.73 | 3.83 | 0.65 | 0.35 | 23.5 |
| Seasonal. | Max. | 83.12 | 76.63 | 73.52 | 82.20 | 75.95 | 71.64 | 81.16 | 73.54 | 70.36 | 79.75 | 72.91 | 70.78 | 75.91 | 71.63 | 69.83 | 81.87 |
| | Min. | 69.72 | 71.71 | 71.43 | 67.98 | 70.92 | 70.39 | 70.94 | 72.08 | 69.84 | 69.52 | 70.90 | 70.13 | 71.95 | 71.13 | 69.49 | 56.60 |
| | Diff. | 13.40 | 4.92 | 2.09 | 14.22 | 5.03 | 1.29 | 10.22 | 1.46 | 0.52 | 10.23 | 2.01 | 0.65 | 3.96 | 0.50 | 0.34 | 25.27 |
| Autumn: | | | | | | | | | | | | | | | | | |
| Sept. | Max. | 71.11 | 67.57 | 66.22 | 71.02 | 67.42 | 65.85 | 69.55 | 65.89 | 65.27 | 69.15 | 65.27 | 65.49 | 67.30 | 65.95 | 65.87 | 73.3 |
| | Min. | 61.41 | 64.05 | 64.74 | 60.40 | 63.70 | 64.85 | 62.25 | 64.78 | 64.66 | 61.72 | 63.78 | 64.81 | 64.04 | 65.30 | 65.51 | 48.7 |
| | Diff. | 9.70 | 3.52 | 1.48 | 10.62 | 3.72 | 1.00 | 7.30 | 1.11 | 0.61 | 7.43 | 1.49 | 0.68 | 3.26 | 0.65 | 0.36 | 24.6 |
| Oct. | Max. | 55.51 | 54.96 | 55.01 | 55.44 | 55.09 | 55.47 | 54.71 | 54.56 | 55.35 | 54.83 | 53.52 | 55.41 | 54.24 | 55.16 | 56.63 | 59.0 |
| | Min. | 50.15 | 52.82 | 53.94 | 49.25 | 52.63 | 54.64 | 50.74 | 53.58 | 54.81 | 50.89 | 52.03 | 54.85 | 52.21 | 54.60 | 56.14 | 41.5 |
| | Diff. | 5.36 | 2.14 | 1.07 | 6 19 | 2.46 | 0.83 | 3.97 | 0.98 | 0.54 | 3 94 | 1.49 | 0.56 | 2.03 | 0.56 | 0.49 | 17.5 |
| Nov. | Max. | 43.63 | 43.57 | 43.80 | 43.70 | 43.88 | 44.82 | 43.25 | 43.64 | 44.02 | 43.65 | 43.28 | 44.77 | 42.56 | 43.60 | 45.68 | 49.0 |
| | Min. | 40.46 | 42.38 | 42.87 | 40.12 | 42.26 | 44.10 | 40.84 | 42.82 | 44.04 | 41.20 | 42.02 | 44.13 | 41.44 | 43.14 | 45.28 | 34.4 |
| | Diff. | 3.17 | 1.19 | 0.93 | 3.58 | 1.62 | 0.72 | 2.41 | 0.82 | 0.58 | 2.45 | 1.26 | 0 64 | 1.12 | 0.55 | 0.40 | 14.6 |
| Seasonal. | Max. | 56.75 | 55.37 | 55.01 | 56.72 | 55.46 | 55.38 | 55.84 | 54.70 | 55.08 | 55.88 | 54.02 | 55.22 | 54.70 | 54.93 | 56.06 | 60.43 |
| | Min. | 50.67 | 53.08 | 53.85 | 49.92 | 52.86 | 54.53 | 51.28 | 53.73 | 54.50 | 51.27 | 52.61 | 54.80 | 52.56 | 54.35 | 55.64 | 41.53 |
| | Diff. | 5.08 | 2.29 | 1.16 | 6.80 | 2.60 | 0.85 | 4.56 | 0.97 | 0.58 | 4.61 | 1.41 | 0.62 | 2.14 | 0.58 | 0.42 | 18.90 |
| Yearly. | Max. | 55.82 | 53.05 | 52.13 | 55.55 | 52.86 | 51.76 | 54.31 | 51.58 | 51.03 | 53.96 | 51.32 | 51.19 | 51.53 | 50.40 | 51.04 | 57.71 |
| | Min. | 48.81 | 50.48 | 50.98 | 47.91 | 50.17 | 50.92 | 49.09 | 50.68 | 50.55 | 48.80 | 50.14 | 50.65 | 49.38 | 49.92 | 50.66 | 37.45 |
| | Diff. | 7.01 | 2.57 | 1.15 | 7.64 | 2.69 | 0.84 | 5.22 | 0.90 | 0.48 | 5.06 | 1.18 | 0.54 | 2.15 | 0.48 | 0.38 | 20.26 |

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TABLE 81.—MONTHLY, SEASONAL AND YEARLY MAXIMUM, MINIMUM AND AMPLITUDE OF TEMPERATURE OF DIFFERENT TYPES OF SOIL, COVERED WITH SAND.

| 1913-1914. | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | 6″ | 12″ | 18″ | |
| Winter: | | | | | | | | | | | | | | | | | |
| Dec. | Max. | 36.75 | 38.34 | 39.32 | 36.42 | 38.52 | 40.70 | 36.67 | 39.05 | 40.83 | 37.02 | 38.91 | 40.64 | 37.48 | 39.94 | 42.26 | 39.1 |
| | Min. | 35.67 | 37.68 | 38.83 | 35.06 | 37.84 | 40.18 | 35.91 | 38.60 | 40.41 | 36.23 | 38.39 | 40.28 | 36.71 | 39.55 | 41.80 | 24.6 |
| | Diff. | 1.08 | 0.66 | 0.49 | 1.36 | 0.68 | 0.52 | 0.76 | 0.45 | 0.42 | 0.79 | 0.52 | 0.44 | 0.77 | 0.39 | 0.46 | 14.5 |
| Jan. | Max. | 33.87 | 34.98 | 35.63 | 33.56 | 35.01 | 36.49 | 33.24 | 34.90 | 36.27 | 34.09 | 35.30 | 36.39 | 33.17 | 34.82 | 36.97 | 33.5 |
| | Min. | 33.55 | 34.64 | 35.35 | 33.22 | 34.69 | 36.28 | 32.89 | 34.71 | 36.14 | 33.76 | 34.99 | 36.21 | 33.00 | 34.68 | 36.82 | 20.5 |
| | Diff. | 0.32 | 0.34 | 0.28 | 0.34 | 0.32 | 0.21 | 0.35 | 0.19 | 0.13 | 0.33 | 0.31 | 0.18 | 0.17 | 0.17 | 0.14 | 13.0 |
| Feb. | Max. | 33.59 | 34.69 | 35.36 | 32.95 | 34.52 | 36.07 | 33.27 | 34.91 | 36.00 | 33.89 | 35.07 | 36.10 | 33.52 | 34.90 | 36.73 | 23.5 |
| | Min. | 33.33 | 34.41 | 35.05 | 32.63 | 34.25 | 35.79 | 32.99 | 34.61 | 35.70 | 33.63 | 34.78 | 35.78 | 33.33 | 34.65 | 36.45 | 1.9 |
| | Diff. | 0.26 | 0.28 | 0.31 | 0.32 | 0.27 | 0.28 | 0.28 | 0.30 | 0.30 | 0.26 | 0.29 | 0.32 | 0.22 | 0.27 | 0.30 | 21.6 |
| Seasonal. | Max. | 34.74 | 36.00 | 36.77 | 34.31 | 36.07 | 37.75 | 34.39 | 36.29 | 37.72 | 35.00 | 36.45 | 37.71 | 34.73 | 36.56 | 38.66 | 32.03 |
| | Min. | 34.18 | 35.56 | 36.41 | 33.64 | 35.58 | 37.42 | 33.93 | 35.97 | 37.44 | 34.54 | 36.02 | 37.40 | 34.31 | 36.27 | 38.31 | 15.67 |
| | Diff. | 0.56 | 0.42 | 0.36 | 0.67 | 0.42 | 0.33 | 0.46 | 0.32 | 0.28 | 0.46 | 0.38 | 0.31 | 0.38 | 0.28 | 0.28 | 16.36 |
| Spring: | | | | | | | | | | | | | | | | | |
| Mar. | Max. | 37.35 | 36.93 | 36.71 | 37.10 | 36.74 | 36.77 | 36.38 | 36.17 | 36.42 | 36.97 | 36.36 | 36.74 | 33.77 | 34.61 | 36.19 | 39.7 |
| | Min. | 34.84 | 35.71 | 36.07 | 34.23 | 35.48 | 36.35 | 34.58 | 35.75 | 36.10 | 35.19 | 35.74 | 36.41 | 33.44 | 34.32 | 35.98 | 22.5 |
| | Diff. | 2.51 | 1.22 | 0.64 | 2.87 | 1.26 | 0.42 | 1.77 | 0.42 | 0.33 | 1.78 | 0.62 | 0.32 | 0.33 | 0.29 | 0.21 | 17.2 |
| Apr. | Max. | 50.26 | 47.17 | 45.52 | 51.19 | 47.39 | 44.81 | 48.66 | 45.18 | 43.43 | 48.42 | 45.08 | 44.00 | 46.02 | 43.41 | 43.05 | 35.2 |
| | Min. | 43.10 | 44.27 | 44.10 | 42.63 | 44.09 | 43.88 | 43.68 | 44.12 | 43.04 | 43.49 | 43.88 | 43.48 | 43.94 | 42.97 | 42.67 | 34.2 |
| | Diff. | 7.16 | 2.90 | 1.42 | 8.56 | 3.30 | 0.93 | 4.98 | 1.06 | 0.39 | 4.93 | 1.20 | 0.52 | 2.08 | 0.44 | 0.38 | 21.0 |
| May. | Max. | 64.42 | 59.67 | 57.31 | 65.80 | 59.88 | 56.14 | 63.18 | 57.49 | 54.64 | 63.50 | 57.45 | 55.78 | 61.25 | 56.68 | 55.02 | 70.6 |
| | Min. | 54.75 | 56.13 | 55.74 | 53.77 | 55.76 | 55.06 | 55.95 | 56.35 | 54.18 | 55.97 | 56.02 | 55.23 | 57.81 | 56.18 | 54.62 | 46.5 |
| | Diff. | 9.67 | 3.54 | 1.57 | 12.03 | 4.12 | 1.08 | 7.23 | 1.14 | 0.46 | 7.53 | 1.43 | 0.52 | 3.44 | 0.50 | 0.47 | 24.1 |
| Seasonal. | Max. | 50.68 | 47.92 | 46.51 | 51.38 | 48.00 | 45.91 | 49.40 | 46.28 | 44.83 | 49.63 | 46.30 | 45.50 | 47.01 | 44.80 | 44.78 | 55.17 |
| | Min. | 44.23 | 45.37 | 45.30 | 43.54 | 45.11 | 45.11 | 44.74 | 45.41 | 44.44 | 44.88 | 45.21 | 45.04 | 45.06 | 44.50 | 44.40 | 34.40 |
| | Diff. | 6.45 | 2.55 | 1.21 | 7.82 | 2.79 | 0.80 | 4.66 | 0.87 | 0.39 | 4.75 | 1.09 | 0.46 | 1.95 | 0.40 | 0.38 | 20.77 |
| Summer: | | | | | | | | | | | | | | | | | |
| June. | Max. | 76.83 | 71.01 | 69.19 | 77.19 | 71.36 | 67.73 | 76.03 | 69.68 | 66.28 | 75.78 | 69.22 | 67.57 | 75.08 | 69.92 | 67.44 | 77.6 |
| | Min. | 66.19 | 67.94 | 67.58 | 65.02 | 67.27 | 66.55 | 67.96 | 68.30 | 65.67 | 67.72 | 67.58 | 66.87 | 70.84 | 69.22 | 67.06 | 54.3 |
| | Diff. | 10.64 | 3.07 | 1.61 | 12.17 | 4.09 | 1.18 | 8.04 | 1.32 | 0.61 | 8.06 | 1.64 | 0.80 | 4.24 | 0.71 | 0.38 | 23.3 |
| July. | Max. | 80.74 | 75.89 | 73.50 | 80.58 | 75.84 | 72.11 | 80.02 | 73.90 | 70.36 | 79.42 | 73.00 | 71.56 | 79.67 | 74.35 | 71.92 | 83.0 |
| | Min. | 70.88 | 72.28 | 71.86 | 69.33 | 71.86 | 70.90 | 72.47 | 72.58 | 69.94 | 71.90 | 71.45 | 71.02 | 75.38 | 73.81 | 71.56 | 59.0 |
| | Diff. | 9.86 | 3.61 | 1.64 | 11.25 | 3.98 | 1.21 | 7.56 | 1.32 | 0.42 | 7.52 | 1.55 | 0.54 | 4.28 | 0.52 | 0.36 | 24.0 |
| Aug. | Max. | 78.00 | 74.07 | 72.41 | 77.89 | 73.90 | 71.57 | 77.43 | 72.72 | 70.59 | 76.64 | 71.83 | 71.53 | 76.20 | 73.48 | 72.30 | 81.0 |
| | Min. | 68.81 | 70.78 | 70.99 | 67.36 | 70.20 | 70.57 | 70.24 | 71.60 | 70.08 | 69.62 | 70.44 | 70.84 | 72.56 | 72.85 | 72.08 | 57.0 |
| | Diff. | 9.19 | 3.29 | 1.42 | 10.53 | 3.64 | 1.00 | 7.24 | 1.13 | 0.51 | 7.02 | 1.39 | 0.69 | 3.64 | 0.63 | 0.38 | 24.0 |
| Seasonal. | Max. | 78.52 | 73.66 | 71.70 | 78.55 | 73.70 | 70.47 | 77.85 | 72.10 | 69.09 | 77.28 | 71.35 | 70.23 | 76.96 | 72.56 | 70.58 | 80.53 |
| | Min. | 68.63 | 70.33 | 70.14 | 67.24 | 69.80 | 69.34 | 70.23 | 70.85 | 68.56 | 69.75 | 69.82 | 69.58 | 72.93 | 71.96 | 70.21 | 56.77 |
| | Diff. | 9.89 | 3.33 | 1.56 | 11.31 | 4.90 | 1.13 | 7.62 | 1.25 | 0.52 | 7.53 | 1.53 | 0.64 | 4.03 | 0.60 | 0.34 | 23.76 |
| Autumn: | | | | | | | | | | | | | | | | | |
| Sept. | Max. | 68.07 | 65.43 | 64.59 | 68.14 | 65.61 | 64.56 | 67.52 | 64.61 | 63.76 | 67.22 | 64.19 | 64.48 | 66.21 | 65.14 | 65.25 | 72.0 |
| | Min. | 59.75 | 62.40 | 63.20 | 57.86 | 62.02 | 63.50 | 61.12 | 63.46 | 63.17 | 60.92 | 62.87 | 63.60 | 62.99 | 64.55 | 64.84 | 48.0 |
| | Diff. | 8.32 | 3.03 | 1.39 | 10.28 | 3.59 | 1.06 | 6.40 | 1.15 | 0.59 | 6.30 | 1.32 | 0.82 | 3.22 | 0.59 | 0.41 | 24.0 |
| Oct. | Max. | 58.71 | 57.76 | 57.74 | 58.60 | 57.80 | 57.81 | 58.05 | 57.22 | 57.34 | 58.37 | 57.00 | 57.97 | 57.78 | 58.17 | 59.21 | 65.0 |
| | Min. | 52.96 | 55.18 | 56.36 | 52.05 | 55.05 | 56.80 | 53.79 | 56.21 | 56.84 | 53.86 | 55.90 | 57.23 | 55.52 | 57.42 | 58.86 | 44.0 |
| | Diff. | 5.75 | 2.58 | 1.38 | 6.55 | 2.75 | 0.91 | 4.29 | 1.01 | 0.50 | 4.51 | 1.16 | 0.74 | 2.26 | 0.75 | 0.35 | 21.0 |
| Nov. | Max. | 40.56 | 41.69 | 42.57 | 39.50 | 41.90 | 43.82 | 40.57 | 42.23 | 43.84 | 41.08 | 42.20 | 44.09 | 40.44 | 43.13 | 45.85 | 47.0 |
| | Min. | 38.00 | 40.36 | 41.78 | 37.06 | 40.44 | 43.18 | 38.68 | 41.55 | 43.37 | 39.10 | 41.43 | 43.57 | 39.30 | 42.74 | 45.43 | 28.0 |
| | Diff. | 2.56 | 1.33 | 0.79 | 2.44 | 1.46 | 0.67 | 1.89 | 0.68 | 0.47 | 1.98 | 0.81 | 0.52 | 1.08 | 0.39 | 0.42 | 19.0 |
| Seasonal. | Max. | 55.78 | 54.96 | 54.97 | 55.41 | 55.10 | 55.40 | 55.38 | 54.66 | 54.96 | 55.56 | 54.60 | 55.51 | 54.81 | 55.48 | 56.77 | 61.33 |
| | Min. | 50.24 | 52.85 | 53.75 | 48.96 | 52.50 | 54.52 | 51.20 | 53.41 | 54.46 | 51.29 | 53.41 | 54.82 | 52.67 | 54.90 | 56.36 | 40.00 |
| | Diff. | 5.54 | 2.31 | 1.19 | 6.42 | 2.60 | 0.88 | 4.18 | 1.25 | 0.52 | 4.27 | 1.09 | 0.69 | 2.19 | 0.58 | 0.39 | 21.33 |
| Yearly. | Max. | 54.93 | 53.14 | 52.45 | 54.91 | 53.21 | 52.38 | 54.20 | 52.37 | 51.89 | 54.37 | 52.11 | 52.24 | 53.38 | 52.38 | 52.66 | 58.27 |
| | Min. | 49.32 | 50.98 | 51.41 | 48.35 | 49.75 | 51.60 | 50.03 | 51.41 | 51.23 | 50.12 | 51.11 | 51.71 | 51.24 | 51.91 | 52.34 | 36.71 |
| | Diff. | 5.59 | 2.16 | 1.04 | 6.56 | 3.46 | 0.78 | 4.23 | 0.93 | 0.42 | 4.25 | 1.03 | 0.53 | 2.14 | 0.47 | 0.34 | 21.56 |

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TABLE 82.—MONTHLY, SEASONAL, AND YEARLY MAXIMUM, MINIMUM AND AMPLITUDE OF TEMPERATURE OF DIFFERENT TYPES OF SOIL, NOT COVERED WITH SAND.

| 1914-1915. | | Gravel. | | | Sand. | | | Loam. | | | Clay. | | | Peat. | | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | 2" | 4" | 6" | |
| Winter: | | | | | | | | | | | | | | | | | |
| Dec. | Max. | 33.02 | 33.57 | 33.96 | 31.58 | 32.31 | 33.36 | 32.79 | 33.74 | 34.06 | 32.80 | 33.21 | 33.89 | 33.55 | 34.18 | 35.55 | 28.0 |
| | Min. | 31.55 | 32.78 | 33.53 | 29.20 | 30.99 | 32.76 | 31.99 | 33.38 | 33.69 | 31.74 | 32.75 | 33.59 | 33.10 | 33.92 | 35.25 | 15 0 |
| | Diff. | 1.47 | 0.79 | 0.43 | 2.38 | 1.32 | 0 60 | 0.80 | 0.36 | 0.37 | 1.06 | 0.46 | 0.30 | 0.45 | 0.26 | 0.30 | 13.0 |
| Jan. | Max. | 31.91 | 32.38 | 32.73 | 30.86 | 31.47 | 32 07 | 31.39 | 32.13 | 32.10 | 31.95 | 32.15 | 32.53 | 32.12 | 32.03 | 32 68 | 28.0 |
| | Min. | 31.72 | 32.20 | 32.56 | 30 38 | 31.13 | 31.84 | 31.21 | 31.97 | 31.94 | 31.79 | 31.94 | 32.39 | 31.99 | 31.84 | 32.52 | 12 9 |
| | Diff. | 0.19 | 0.18 | 0.17 | 0.48 | 0.34 | 0.23 | 0.18 | 0.16 | 0.16 | 0.16 | 0.21 | 0.14 | 0.13 | 0.19 | 0.16 | 15 1 |
| Feb. | Max. | 32.76 | 33.01 | 33.13 | 32.86 | 33.13 | 33.40 | 31.82 | 32.26 | 32.08 | 32.49 | 32.48 | 32.87 | 32.20 | 31.83 | 32.47 | 36.2 |
| | Min. | 31 43 | 32 41 | 32 80 | 31.14 | 32.23 | 32.88 | 31.06 | 32.02 | 31.86 | 31.66 | 32.16 | 32.62 | 31.56 | 31.65 | 32.35 | 22.5 |
| | Diff. | 1.33 | 0.60 | 0.33 | 1.72 | 0.90 | 0.52 | 0.76 | 0.24 | 0.22 | 0.83 | 0.32 | 0.25 | 0.64 | 0.18 | 0.12 | 13.7 |
| **Seasonal.** | **Max.** | **32.56** | **32.99** | **33.27** | **31.77** | **32.30** | **32.94** | **32.00** | **32.71** | **32.75** | **32.41** | **32.61** | **33.10** | **32.62** | **32.68** | **33.57** | **30.73** |
| | **Min.** | **31.57** | **32.46** | **32.94** | **30.24** | **31.45** | **32.49** | **31.42** | **32.46** | **32.50** | **31.73** | **32.26** | **32.87** | **32.22** | **32.49** | **33.37** | **16.80** |
| | **Diff.** | **0.99** | **0.53** | **0.33** | **1.53** | **0.85** | **0.45** | **0.58** | **0.25** | **0.25** | **0.68** | **0.35** | **0.23** | **0.40** | **0.19** | **0.20** | **13.93** |
| Spring: | | | | | | | | | | | | | | | | | |
| Mar. | Max. | 37.01 | 36 04 | 36.29 | 36.92 | 36.99 | 36.81 | 35.28 | 35.28 | 34.38 | 35.70 | 35.14 | 34.80 | 32.29 | 31.82 | 32.32 | 39.6 |
| | Min. | 30.48 | 32 06 | 32.90 | 30.50 | 32.07 | 33.18 | 31.24 | 33.01 | 32.91 | 31.74 | 32.71 | 33.31 | 31.36 | 31.43 | 32.16 | 20.6 |
| | Diff. | 6.53 | 4.58 | 3.39 | 6.42 | 4.92 | 3.63 | 4.04 | 2.27 | 1.47 | 3.96 | 2.43 | 1.49 | 0.93 | 0.39 | 0.16 | 19.0 |
| Apr. | Max. | 63.56 | 60.20 | 57.69 | 63.46 | 60.85 | 58.63 | 61.36 | 57.48 | 53.22 | 59.81 | 56.42 | 53.97 | 53.88 | 48.78 | 46.70 | 63 0 |
| | Min. | 45.63 | 46.45 | 47.34 | 45.38 | 46.02 | 47.11 | 45.99 | 47.55 | 47.51 | 45.88 | 46.62 | 47.99 | 44.63 | 44.38 | 45.15 | 40 1 |
| | Diff. | 17.93 | 13.75 | 10.35 | 18.08 | 14.83 | 11.52 | 15.37 | 9.93 | 5.71 | 13.93 | 9.80 | 5.98 | 9.25 | 4.40 | 1.55 | 22.9 |
| May. | Max. | 65.18 | 62.45 | 61.09 | 65.80 | 63.54 | 61.96 | 62.63 | 60.36 | 57.00 | 62.09 | 59.15 | 57.79 | 61.44 | 58.22 | 55.65 | 62.3 |
| | Min. | 48.42 | 49.67 | 51.00 | 47.86 | 48.66 | 50.25 | 48.41 | 50.98 | 51.65 | 48.94 | 49.75 | 51.69 | 48.93 | 51.43 | 53.71 | 40.7 |
| | Diff. | 16.76 | 12.78 | 10.09 | 17.94 | 14.88 | 11.71 | 14.22 | 9.38 | 5.35 | 13.15 | 9.40 | 6.10 | 12.51 | 6.79 | 1.94 | 21.6 |
| **Seasonal.** | **Max.** | **56.28** | **53.10** | **51.69** | **55.39** | **53.79** | **52.47** | **53.09** | **51.04** | **48.20** | **52.53** | **50.24** | **48.85** | **49.20** | **46.27** | **44.90** | **54.97** |
| | **Min.** | **41.51** | **42.73** | **43.75** | **41.25** | **42.25** | **43.52** | **41.88** | **43.85** | **44.03** | **42.19** | **43.03** | **44.33** | **41.63** | **42.42** | **43.67** | **33.80** |
| | **Diff.** | **13.77** | **10.37** | **7.94** | **14.14** | **11.54** | **8.95** | **11.21** | **7.19** | **4.17** | **10.34** | **7.21** | **4.52** | **7.57** | **3.85** | **1.23** | **21.17** |
| Summer: | | | | | | | | | | | | | | | | | |
| June | Max. | 77.73 | 73.87 | 71.27 | 78.25 | 75.40 | 73.10 | 74.40 | 71.26 | 66.82 | 73.86 | 70.19 | 67.73 | 73.95 | 68.33 | 65.07 | 72.7 |
| | Min. | 57.61 | 57.90 | 59.84 | 56.73 | 57.35 | 59.01 | 57.07 | 59.93 | 60.72 | 57.82 | 58.78 | 60.88 | 57.42 | 60.36 | 62.67 | 49.3 |
| | Diff. | 20 12 | 15.97 | 11.43 | 21.52 | 18.05 | 14.09 | 17.33 | 11.33 | 6.10 | 16.04 | 11.41 | 6.85 | 16.53 | 8.02 | 2.40 | 23.4 |
| July | Max. | 83 29 | 80.19 | 77.41 | 84.41 | 81.91 | 79.45 | 79.80 | 77.50 | 73.27 | 80.54 | 76.36 | 74.47 | 80.52 | 75.28 | 71 62 | 77 9 |
| | Min. | 63.88 | 64 84 | 66.18 | 63.54 | 64.07 | 65.56 | 62.73 | 66.42 | 66.91 | 65 03 | 64.86 | 67.28 | 64.24 | 67.07 | 69.10 | 57.9 |
| | Diff. | 19.41 | 15 35 | 11.23 | 20.87 | 16.84 | 13.89 | 17.07 | 11.08 | 6.36 | 15.51 | 11.50 | 7.19 | 16.28 | 8.21 | 2.52 | 20.0 |
| Aug. | Max. | 76.90 | 74 07 | 72.42 | 78.01 | 75 48 | 73.94 | 73.57 | 71.84 | 68.75 | 74.32 | 72 00 | 70.14 | 74.74 | 70.92 | 68.45 | 73.3 |
| | Min. | 60 42 | 61 76 | 63.61 | 59.41 | 60.65 | 62.75 | 59.79 | 63.12 | 64.03 | 60.95 | 62.84 | 64.63 | 60.34 | 64.17 | 66.18 | 53 6 |
| | Diff. | 16.48 | 12 31 | 8.81 | 18.60 | 14.83 | 11.19 | 13.78 | 8.72 | 4.72 | 13.37 | 9,16 | 5.51 | 14.40 | 6.75 | 2.27 | 19.7 |
| **Seasonal.** | **Max.** | **79.31** | **76.04** | **73.70** | **80.22** | **77.60** | **75.50** | **75.92** | **73.53** | **69.61** | **76.24** | **72.85** | **70.78** | **76.40** | **71.53** | **68.38** | **74.63** |
| | **Min.** | **60.64** | **61.50** | **63.21** | **59.89** | **60.89** | **62.44** | **58.86** | **63.16** | **63.89** | **61.27** | **62.16** | **64.26** | **60.67** | **63.53** | **65.98** | **53.60** |
| | **Diff.** | **18.67** | **14.54** | **10.49** | **20.33** | **16.91** | **13.06** | **16.06** | **10.37** | **5.72** | **14.97** | **10.69** | **6.52** | **15.73** | **8.00** | **2.40** | **21.03** |
| Autumn: | | | | | | | | | | | | | | | | | |
| Sept. | Max. | 74.95 | 71 50 | 69 71 | 76.52 | 73.53 | 71.62 | 73.00 | 69.93 | 66.70 | 71.97 | 69.30 | 67.45 | 72.35 | 68.12 | 65.84 | 73.8 |
| | Min. | 57.44 | 58 85 | 60.48 | 56.57 | 57.88 | 59.78 | 58.02 | 60.48 | 61.36 | 58.12 | 60.01 | 61.61 | 57.76 | 61.17 | 63.52 | 52.6 |
| | Diff. | 17.51 | 12 65 | 9.23 | 19.95 | 15.65 | 11.84 | 14.98 | 9.45 | 5.34 | 13.85 | 9.29 | 5.84 | 14.59 | 6.95 | 2.32 | 21.2 |
| Oct. | Max. | 59 58 | 56 98 | 56 19 | 60.40 | 58.18 | 57.15 | 57.57 | 55.82 | 53.86 | 56 71 | 55.00 | 54.17 | 56.73 | 54.18 | 52.85 | 61.2 |
| | Min. | 47.15 | 48 05 | 49.34 | 46.17 | 47.14 | 48.57 | 47.01 | 48.83 | 49.57 | 47.21 | 48.55 | 49.79 | 46.46 | 49.03 | 51.13 | 41 0 |
| | Diff. | 12.43 | 8.93 | 6.85 | 14.23 | 11.04 | 8.58 | 10.56 | 6.99 | 3.29 | 9.50 | 6.45 | 4.38 | 10.27 | 5.15 | 1.72 | 20.2 |
| Nov. | Max. | 44.42 | 43.42 | 43.25 | 44 59 | 42.78 | 43.65 | 43.18 | 42.89 | 42 34 | 43.37 | 42.66 | 42.75 | 42.35 | 41.88 | 42.48 | 47.4 |
| | Min. | 38.20 | 39.00 | 40 15 | 37.16 | 38.29 | 39.73 | 37.78 | 39.64 | 40.35 | 38.03 | 39.44 | 40.54 | 37.91 | 39.82 | 41.42 | 32.1 |
| | Diff. | 6.22 | 4.42 | 3.10 | 7.43 | 4.49 | 3.92 | 5.40 | 3.25 | 1.99 | 5.34 | 3.22 | 2.21 | 4.44 | 2.06 | 1.06 | 15.3 |
| **Seasonal.** | **Max.** | **59.65** | **57.30** | **56.38** | **60.50** | **58.16** | **57.47** | **57.92** | **56.21** | **54.30** | **57.35** | **55.65** | **54.79** | **57.14** | **54.73** | **53.72** | **60.80** |
| | **Min.** | **47.60** | **48.63** | **49.99** | **46.63** | **47.77** | **49.36** | **47.60** | **49.65** | **50.43** | **47.79** | **49.33** | **50.61** | **47.38** | **50.01** | **52.02** | **41.90** |
| | **Diff.** | **12.05** | **8.67** | **6.39** | **13.87** | **10.39** | **8.11** | **10.32** | **6.56** | **3.87** | **9.56** | **6.32** | **4.18** | **9.76** | **4.72** | **1.70** | **18.90** |
| **Yearly.** | **Max.** | **56.70** | **54.86** | **53.76** | **56.97** | **55.46** | **54.60** | **54.73** | **53.37** | **51.22** | **54.63** | **52.86** | **51.88** | **53.84** | **51.30** | **50.14** | **55.28** |
| | **Min.** | **45.33** | **46.33** | **47.47** | **44.50** | **45.54** | **46.95** | **45.19** | **47.28** | **47.71** | **45.75** | **46.70** | **48.02** | **45.48** | **47.11** | **48.76** | **36.53** |
| | **Diff.** | **11.37** | **8.53** | **6.29** | **12.47** | **9.92** | **7.65** | **9.54** | **6.09** | **3.51** | **8.88** | **6.16** | **3.86** | **8.36** | **4.19** | **1.38** | **18.75** |

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The principal facts revealed by the preceding tables may be summarized as follows: (1) The highest seasonal amplitude occurred in the summer, the smallest in the winter and an intermediate between these two in the spring and autumn. The magnitude of the spring and fall fluctuation was about equal and only about half as great as that of the summer; while, the yearly average amplitude was equal in magnitude to that of the spring or fall. (2) The amplitude of the air was far greater than that of any soil at any depth.

## ADDITIONAL EXPERIMENTAL DATA ON THE TEMPERATURE OF SAND WITH DIFFERENT AMOUNTS OF ORGANIC MATTER, AT VARIOUS DEPTHS FOR 1913, 1914, AND 1915.

### PLAN OF THE EXPERIMENT.

Organic matter possesses two physical properties which exert a very marked influence upon soil temperature. These are color and water-holding capacity. The soils with the largest amount of organic matter will have the darkest color. Since dark color possesses the highest absorbing capacity for heat these soils will tend to be much warmer, during the insolation, than the light colored soils, which reflect a large amount of the solar rays. On the other hand, the soils with the greatest organic matter content will carry also the highest amount of water and water possessing such great specific heat, latent heat of evaporation, and other properties, will tend to keep the temperature of these soils low.

It was in order to ascertain to what extent these two physical properties of the organic matter would oppose each other and which one would predominate, that the following experiment was undertaken. It consisted of measuring the temperature of a soil to which was added different amounts of organic matter (peat). It was prepared by making a long trench over 3 feet deep and 3 feet wide, placing in it, about a foot apart, wooden boxes 3x3x3 feet without bottom and top and filling them with a sandy soil. The soils of the upper 24 inches were then taken out from all the boxes, except one, each soil was thoroughly mixed with the proper amount of peat, and then placed back into its respective box. There were six boxes, one containing soil to which was added no peat, another contained only peat, and the other four had soil with various proportions of peat. The percentage of total organic matter of the various soils, except peat, as determined by the ignition method is shown by the following figures: 1.81, 2.01, 3.32, 5.47, and 6.95%. To the soil showing 1.81% organic matter no peat was added. This amount of organic matter, therefore, was originally present in the soil. This untreated soil was covered with a thin layer of white quartz sand so as to give it a distinct white color. The color of the various soils, therefore, ranged from very white to very black.

The temperature was measured in all the soils at two different depths every day except Sunday for almost four years. It was recorded by means of the electric thermometers already described. During the years

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of 1912, 1913, and 1914 it was measured at the depths of 5 and 18 inches, but during 1915, at 3 and 6 inches. All the records were made three times a day, morning, noon and evening. The time, however, was so chosen and varied during the different seasons as to obtain very close the actual maximum and minimum temperature.

The data for the first year (1912) has been published in the previous report. In the present paper the results of the other three years will be presented.

On account of limited space the daily average, maximum and minimum temperature have been eliminated and only the monthly, seasonal and yearly will be presented here. These data are submitted in the following pages.

MONTHLY, SEASONAL AND YEARLY AVERAGE TEMPERATURE FOR 1913, 1914 AND 1915.

TABLE 83.—MONTHLY, SEASONAL, AND YEARLY AVERAGE TEMPERATURE OF SOIL WITH DIFFERENT AMOUNTS OF ORGANIC MATTER.

| 1912-1913 | 1.81% Org. Mat. | | 2.01% Org. Mat. | | 3.32% Org. Mat. | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Peat. | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5" | 18" | 5" | 18" | 5" | 18" | 5" | 18" | 5" | 18" | 5" | 18" | |
| Winter: | | | | | | | | | | | | | |
| December.. | 31.81 | 35.42 | 32.87 | 36.50 | 32.99 | 37.00 | 33.25 | 37.00 | 33.43 | 37.17 | 34.18 | 38.13 | 31 0 |
| January.... | 30.68 | 33.58 | 31.54 | 34.46 | 31.75 | 34.95 | 32.00 | 34.95 | 31.99 | 35.02 | 32 18 | 35.71 | 26 2 |
| February... | 26.19 | 30.50 | 26.88 | 31.52 | 27.10 | 31.93 | 27.53 | 31.73 | 27.48 | 31.99 | 28.66 | 33.23 | 20.0 |
| **Ave.** | **29.56** | **33.17** | **30.43** | **34.16** | **30.61** | **34.63** | **30.93** | **34.56** | **30.97** | **34.73** | **31.67** | **35.69** | **25.73** |
| Spring: | | | | | | | | | | | | | |
| March .... | 33.94 | 33.70 | 34.66 | 34.16 | 34.73 | 34 47 | 34.55 | 33.93 | 34.32 | 33.27 | 32.91 | 32.12 | 31 0 |
| April .... | 48.50 | 45.04 | 50.34 | 45.63 | 49.83 | 45.73 | 49.76 | 45.90 | 49.51 | 45.29 | 42 24 | 40.09 | 45.9 |
| May..... | 60.19 | 56.54 | 62.08 | 57.21 | 62.09 | 57.47 | 61.98 | 57.08 | 61.85 | 56 75 | 59 38 | 55.33 | 56 2 |
| **Ave ....** | **47.54** | **45.09** | **49.03** | **45.67** | **48.88** | **45.89** | **48.76** | **45.64** | **48.56** | **45.10** | **44.84** | **42.51** | **44.37** |
| Summer: | | | | | | | | | | | | | |
| June ..... | 72.65 | 67.75 | 74.85 | 69.37 | 75.43 | 69.26 | 75.82 | 68.67 | 75.77 | 68 17 | 71.21 | 65.03 | 67.6 |
| July ..... | 77.61 | 73.86 | 78.44 | 75.16 | 79.09 | 74.67 | 79 17 | 74.01 | 79.10 | 73.55 | 75.90 | 71.69 | 70.8 |
| Aug..... | 75.74 | 72.81 | 76.86 | 74.25 | 77.56 | 73.69 | 77 06 | 73.16 | 76.96 | 72.77 | 74.39 | 71.75 | 69.4 |
| **Ave.....** | **75.33** | **74.81** | **76.72** | **72.93** | **77.36** | **72.54** | **77.35** | **71.95** | **77.28** | **71.50** | **73.83** | **69.49** | **69.27** |
| Autumn: | | | | | | | | | | | | | |
| September. | 65.99 | 64.94 | 66.96 | 66.62 | 67.12 | 65.96 | 67.07 | 65.78 | 67.15 | 65.52 | 65.82 | 65.12 | 61.0 |
| October.... | 53.28 | 54 39 | 53.86 | 56.21 | 53.92 | 55 32 | 53 86 | 55 40 | 53.84 | 56.20 | 54.01 | 55.90 | 50 2 |
| November.. | 42.57 | 43.71 | 43.45 | 45 91 | 43.53 | 45.03 | 42.82 | 45.18 | 43.44 | 45.20 | 43.14 | 45.11 | 41.7 |
| **Ave .....** | **53.95** | **55.68** | **54.76** | **56.25** | **54.86** | **55.44** | **54.58** | **55.45** | **54.81** | **55.64** | **54.32** | **55.32** | **50.97** |
| **Yearly ave..** | **51.60** | **52.19** | **52.84** | **52.25** | **52.93** | **52.13** | **52.91** | **51.90** | **52.91** | **51.74** | **51.17** | **50.77** | **47.58** |

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TABLE 83—1913-1914.—*Continued.*

| 1913-1914 | 1.81% Org. Mat. | | 2.01% Org. Mat. | | 3.32% Org. Mat. | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Peat. | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | |
| Winter: | | | | | | | | | | | | | |
| December.. | 36.14 | 39.25 | 37.13 | 41.42 | 37.14 | 40.53 | 36.89 | 40.72 | 37.45 | 41.56 | 38.70 | 41.74 | 31.8 |
| January.... | 33.13 | 35.33 | 34.13 | 36.33 | 34.18 | 36.46 | 34.26 | 36.64 | 34.21 | 36.61 | 34.06 | 36.42 | 27.0 |
| February... | 32.24 | 34.94 | 33.36 | 35.84 | 33.63 | 36.10 | 34.03 | 36.38 | 34.34 | 36.50 | 34.48 | 36.30 | 12.7 |
| **Ave.....** | **33.84** | **36.51** | **34.87** | **37.86** | **34.98** | **37.70** | **35.06** | **37.91** | **35.33** | **38.22** | **35.75** | **38.15** | **23.83** |
| Spring: | | | | | | | | | | | | | |
| Mar..... | 35.41 | 36.06 | 36.53 | 36.72 | 36.47 | 37.02 | 36.70 | 37.24 | 36.66 | 37.15 | 34.72 | 35.85 | 31.1 |
| April..... | 47.26 | 44.83 | 47.78 | 45.01 | 47.60 | 45.20 | 47.31 | 44.82 | 47.00 | 44.48 | 45.17 | 42.73 | 44.7 |
| May..... | 61.83 | 57.06 | 62.62 | 57.15 | 62.61 | 57.43 | 62.54 | 56.91 | 62.20 | 56.52 | 59.11 | 54.54 | 58.6 |
| **Ave.....** | **48.17** | **45.98** | **48.98** | **46.29** | **48.89** | **46.55** | **48.85** | **46.32** | **48.62** | **46.05** | **46.33** | **44.37** | **44.80** |
| Summer: | | | | | | | | | | | | | |
| June..... | 71.19 | 67.38 | 74.07 | 68.34 | 74.29 | 68.90 | 74.66 | 68.53 | 74.67 | 68.22 | 71.71 | 66.47 | 66.0 |
| July..... | 76.35 | 72.15 | 78.03 | 72.48 | 77.66 | 72.97 | 78.57 | 72.66 | 78.71 | 72.42 | 75.87 | 70.70 | 71.0 |
| August..... | 72.52 | 70.96 | 74.98 | 71.62 | 74.37 | 71.89 | 74.40 | 71.57 | 74.47 | 71.52 | 73.13 | 70.78 | 68.9 |
| **Ave.....** | **73.35** | **70.16** | **75.69** | **70.81** | **75.44** | **71.25** | **75.88** | **70.92** | **75.95** | **70.72** | **73.57** | **69.32** | **68.63** |
| Autumn: | | | | | | | | | | | | | |
| Sept..... | 63.56 | 63.42 | 65.26 | 64.12 | 64.88 | 64.37 | 65.08 | 64.36 | 65.14 | 64.48 | 64.36 | 63 96 | 60.3 |
| October.... | 55.56 | 56.50 | 56.70 | 57.26 | 56.68 | 57.44 | 56.85 | 57.75 | 56.90 | 57.92 | 56.65 | 57.90 | 54 6 |
| November.. | 38.98 | 42.06 | 40.42 | 43.26 | 40.32 | 43.45 | 40.50 | 43.86 | 40.55 | 44.39 | 41.13 | 44.72 | 37 6 |
| **Ave.....** | **52.70** | **53.99** | **54.13** | **54.88** | **53.96** | **55.09** | **54.14** | **55.32** | **54.20** | **55.60** | **54.05** | **55.53** | **50.83** |
| **Yearly Ave..** | **52.02** | **51.66** | **53.42** | **52.46** | **53.32** | **52.65** | **53.48** | **52.62** | **53.53** | **52.65** | **52.43** | **51.84** | **47.02** |

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TABLE 83—1914-1915.—*Concluded.*

| 1914-1915 | 1.81% Org. Mat. | | 2.01% Org. Mat. | | 3.32% Org. Mat. | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Peat. | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3" | 6" | 3" | 6" | 3" | 6" | 3" | 6" | 3" | 6" | 3" | 6" | |
| Winter: | | | | | | | | | | | | | |
| December.. | 31.35 | 33.35 | 32.53 | 34.00 | 33.07 | 34.51 | 33.47 | 34.49 | 34.13 | 35.05 | 34.87 | 35.57 | 21.6 |
| January.... | 30.28 | 31.48 | 31.53 | 32.52 | 32.13 | 33.24 | 32.63 | 33.27 | 32.86 | 33.46 | 32.76 | 32.78 | 20.4 |
| February... | 31.75 | 32.70 | 32.95 | 33.51 | 33.12 | 33.85 | 33.28 | 33.64 | 33.29 | 33.66 | 32.63 | 32.35 | 29.4 |
| Ave..... | 31.13 | 32.51 | 32.34 | 33.34 | 32.77 | 33.87 | 33.13 | 33.80 | 33.43 | 34.06 | 33.42 | 33.57 | 23.80 |
| Spring: | | | | | | | | | | | | | |
| Mar..... | 34.10 | 34.71 | 35.18 | 35.23 | 34.88 | 35.38 | 34.90 | 35.13 | 35.00 | 35.39 | 32.57 | 32.11 | 30.1 |
| April..... | 55.09 | 52.97 | 56.72 | 53.60 | 56.10 | 53.85 | 55.64 | 53.12 | 54.95 | 52.64 | 49.40 | 45.83 | 51.6 |
| May..... | 56.60 | 55.94 | 59.65 | 57.50 | 59.02 | 57.58 | 58.84 | 57.02 | 58.56 | 57.96 | 56.39 | 53.62 | 51.5 |
| Ave..... | 48.60 | 47.87 | 50.52 | 48.78 | 50.00 | 48.94 | 49.79 | 48.42 | 49.50 | 48.66 | 46.12 | 43.89 | 44.40 |
| Summer: | | | | | | | | | | | | | |
| June ..... | 67.82 | 66.07 | 70.00 | 67.21 | 69.51 | 67.39 | 69.17 | 66.76 | 69.16 | 65.86 | 66.28 | 62.25 | 61.0 |
| July..... | 72.83 | 71.73 | 75.88 | 73.30 | 75.43 | 73.45 | 75.44 | 73.05 | 75.11 | 72.33 | 72.90 | 68.76 | 67.9 |
| August..... | 69.43 | 68.70 | 71.80 | 69.71 | 71.28 | 70.07 | 71.35 | 69.50 | 70.94 | 68.91 | 69.20 | 66.51 | 63.4 |
| Ave ..... | 70.03 | 68.83 | 72.56 | 70.07 | 72.07 | 70.30 | 71.99 | 69.77 | 71.74 | 69.03 | 69.46 | 65.84 | 64.10 |
| Autumn: | | | | | | | | | | | | | |
| September.. | 66.80 | 65.89 | 68.78 | 66.83 | 68.36 | 67.07 | 68.46 | 66.64 | 68.03 | 66.06 | 66.20 | 63.40 | 63.2 |
| October.... | 52.98 | 52.99 | 54.64 | 53.63 | 54.50 | 54.09 | 55.05 | 53.80 | 54.60 | 53.47 | 52.81 | 51.33 | 51.1 |
| November.. | 40.80 | 42.02 | 42.41 | 42.60 | 42.22 | 42.93 | 42.70 | 42.89 | 42.71 | 42.91 | 42.04 | 42.24 | 39.8 |
| Ave..... | 53.53 | 53.63 | 55.28 | 54.35 | 55.03 | 54.69 | 55.40 | 54.44 | 55.11 | 54.15 | 53.68 | 52.32 | 51.37 |
| Yearly ave. | 50.82 | 50.71 | 52.68 | 51.66 | 52.47 | 51.95 | 52.58 | 51.35 | 52.45 | 51.48 | 50.67 | 48.91 | 45.92 |

Table 83 contains the monthly, seasonal and yearly average temperature for the second year, December 1912 to November 1913. The data show that the temperature of all the soils at the 5-inch depth either completely or almost reached the freezing point in December. During January it remained at or slightly below the freezing point. In February, however, it fell several degrees below this point and was lowest in the soil to which was added no peat, slightly higher in the treated soils and highest in peat. As a matter of fact throughout the winter months peat remained the warmest followed by the soils with an increasing organic matter content. The difference, however, was comparatively very small. The temperature at the 18-inch depth of all the soils reached the freezing point in February.

In March all the soils at both depths had thawed except peat at the 18-inch depth. By April, however, peat also had completely thawed but its temperature was about 7°F lower than that of the other soils at the 5-inch depth and about 5°F at the 18-inch depth. By May the tempera-

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ture of the peat approached that of the other soils quite close so that the difference was only about 1 or 2°F at both depths. From this month on the various soils divided themselves into two distinct groups as regards their temperature. The sand or untreated soil and the peat maintained a low but almost equal temperature and the soils possessing organic matter in percentages of 2.08, 3.32, 5.47, and 6.95 had a slightly higher temperature but also of practically equal magnitude. Thus, in the month of July, when the highest average temperature was attained, the various soils had the following degree of temperature at the 5 and 18-inch depths, respectively: 1.81% organic matter 77.61°, 73.86°; 2.08% 78.47°, 75.16°; 3.32% 79.09°, 74.67°; 5.47% 79.17°, 74.01°; 6.95% 79.10°, 73.55°; and, peat 75.90°, 71.69°F. In this month the difference in temperature between the sand and peat was greater than at any other month during the summer and fall. The above division or order continued, with small variation, until October, and then the magnitude became more or less equal in all the soils. From October until December, the end of the year, all the soils had approximately the same average temperature.

The data for the third year or cycle are contained also in Table 83. The results of this year reveal exactly the same principles as those of the second year just discussed and consequently need no detailed consideration.

The results of the fourth year are represented at the bottom of Table 83. These records differ from those of the previous years in that they were obtained at 3 and 6-inch depths instead of 5 and 18. Even then, however, the order and behavior of the average temperature at these upper depths agree with those of the lower depths of the preceding years and consequently reveal practically the same principles.

It should be noted that the average air temperature was lower than that of all the soils at both depths every month in the year throughout the three years.

In the spring all the soils with the exception of peat, thawed at about the same time; peat, however, thawed much later.

This investigation goes to prove then that soils either with white color and low moisture content or with black color and high water content have a lower average temperature during the spring and summer than soils possessing these properties in medium proportion. In other words the white color of a soil reflects so much of the sun's rays that it prevents the soils from attaining a high temperature in spite of its low water content and small amount of evaporation, while the excess of water content of a black soil, such as peat, consumes so much of the heat energy in its evaporation process that it keeps the temperature of the soil low in spite of its black color and hence its great heat absorbing power.

### MONTHLY, SEASONAL, AND YEARLY MAXIMUM, MINIMUM, AND AMPLITUDE OF TEMPERATURE.

Next, the monthly, seasonal and yearly maximum, minimum and amplitude of temperature of the foregoing various soils for the three years will be considered. These data are shown in Tables 84, 85 and 86, inclusive.



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TABLE 84.—MONTHLY, SEASONAL, AND YEARLY MAXIMUM, MINIMUM AND AMPLITUDE OF TEMPERATURE OF SOIL WITH VARIOUS AMOUNTS OF ORGANIC MATTERS.

| 1912–1913. | | 1.81% Org. Mat. | | 2.01% Org. Mat. | | 3.32% Org. Mat. | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Peat. | | Air |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | |
| Winter: | | | | | | | | | | | | | | |
| December.. | Max..... | 33.00 | 35.79 | 33.75 | 36.81 | 33.79 | 37.28 | 34.03 | 37.29 | 34.06 | 37.44 | 34.50 | 38.34 | 38.1 |
| | Min..... | 30.57 | 35.05 | 31.67 | 36.18 | 31.88 | 36.71 | 32.48 | 36.70 | 32.82 | 36.88 | 33.80 | 37.91 | 23.9 |
| | Diff..... | 2.43 | 0.74 | 2.08 | 0.63 | 1.91 | 0.57 | 1.55 | 0.59 | 1.24 | 0.56 | 0.70 | 0.43 | 14.2 |
| January.... | Max..... | 31.07 | 33.78 | 31.87 | 34.63 | 32.01 | 35.10 | 32.28 | 35.11 | 32.27 | 35.17 | 32.36 | 35.85 | 34.2 |
| | Min..... | 30.15 | 33.40 | 31.11 | 34.27 | 31.35 | 34.78 | 31.64 | 34.79 | 31.65 | 34.86 | 32.00 | 35.55 | 18.2 |
| | Diff..... | 0.92 | 0.38 | 0.76 | 0.36 | 0.66 | 0.32 | 0.64 | 0.32 | 0.62 | 0.31 | 0.36 | 0.30 | 16.0 |
| February... | Max..... | 27.78 | 30.85 | 28.65 | 31.78 | 29.00 | 32.16 | 29.21 | 31.96 | 29.21 | 32.26 | 29.60 | 33.41 | 27.9 |
| | Min..... | 24.14 | 30.04 | 24.54 | 31.21 | 24.57 | 31.69 | 25.33 | 31.46 | 25.17 | 31.75 | 27.56 | 33.05 | 12.1 |
| | Diff..... | 3.64 | 0.81 | 4.11 | 0.57 | 4.43 | 0.47 | 3.88 | 0.50 | 4.04 | 0.51 | 2.04 | 0.36 | 15.8 |
| **Seasonal...** | **Max.....** | **30.62** | **33.47** | **31.42** | **34.41** | **31.60** | **34.85** | **31.84** | **34.79** | **31.85** | **34.96** | **32.15** | **35.87** | **33.40** |
| | **Min.....** | **29.29** | **32.83** | **29.11** | **33.89** | **29.27** | **34.39** | **29.82** | **34.32** | **29.88** | **34.50** | **31.12** | **35.50** | **18.07** |
| | **Diff.....** | **2.33** | **0.64** | **2.31** | **0.52** | **2.33** | **0.46** | **2.02** | **0.47** | **1.97** | **0.46** | **1.03** | **0.37** | **15.33** |
| Spring: | | | | | | | | | | | | | | |
| Mar..... | Max..... | 35.41 | 34.14 | 36.04 | 34.51 | 35.81 | 34.78 | 35.40 | 34.18 | 35.10 | 33.47 | 32.33 | 33.10 | 41.6 |
| | Min..... | 32.42 | 33.35 | 33.31 | 33.84 | 33.54 | 34.19 | 33.68 | 33.68 | 33.53 | 33.06 | 31.91 | 32.73 | 20.5 |
| | Diff..... | 2.99 | 0.79 | 2.73 | 0.67 | 2.27 | 0.59 | 1.72 | 0.50 | 1.57 | 0.41 | 0.42 | 0.37 | 21.1 |
| April..... | Max..... | 52.86 | 46.32 | 55.20 | 46.66 | 54.62 | 46.57 | 54.62 | 46.54 | 54.25 | 45.77 | 43.85 | 40.39 | 56.6 |
| | Min..... | 42.36 | 44.15 | 43.42 | 44.86 | 43.75 | 45.12 | 44.23 | 45.27 | 44.32 | 44.78 | 41.35 | 39.83 | 35.2 |
| | Diff..... | 10.50 | 2.17 | 11.78 | 1.80 | 10.87 | 1.45 | 10.39 | 1.27 | 9.93 | 0.99 | 2.50 | 0.56 | 21.4 |
| May..... | Max..... | 65.64 | 57.83 | 67.48 | 58.19 | 67.64 | 58.47 | 67.30 | 57.77 | 67.28 | 57.23 | 61.48 | 55.44 | 67.2 |
| | Min..... | 53.63 | 55.65 | 54.88 | 56.39 | 54.99 | 56.67 | 55.60 | 56.47 | 55.53 | 56.32 | 58.00 | 55.13 | 45.1 |
| | Diff..... | 12.01 | 2.18 | 12.60 | 1.80 | 12.65 | 1.80 | 11.70 | 1.30 | 11.75 | 0.91 | 3.48 | 0.31 | 22.1 |
| **Seasonal...** | **Max.....** | **51.30** | **46.10** | **52.91** | **46.45** | **52.69** | **46.61** | **52.44** | **46.16** | **52.21** | **45.49** | **45.89** | **42.98** | **55.13** |
| | **Min.....** | **42.80** | **44.38** | **43.87** | **45.03** | **44.09** | **45.33** | **44.50** | **45.14** | **44.49** | **44.72** | **43.75** | **42.56** | **33.60** |
| | **Diff.....** | **8.50** | **1.72** | **9.04** | **1.42** | **8.60** | **1.28** | **7.94** | **1.02** | **7.72** | **0.77** | **2.14** | **0.42** | **21.53** |
| Summer: | | | | | | | | | | | | | | |
| June..... | Max..... | 78.36 | 69.30 | 81.21 | 70.49 | 81.96 | 70.65 | 82.36 | 69.46 | 82.61 | 68.62 | 74.45 | 65.16 | 81.5 |
| | Min..... | 65.28 | 66.70 | 67.03 | 68.42 | 67.18 | 68.18 | 67.94 | 67.83 | 67.80 | 67.58 | 69.28 | 64.88 | 53.7 |
| | Diff..... | 13.08 | 2.60 | 14.18 | 2.07 | 14.78 | 2.47 | 14.42 | 1.63 | 14.81 | 1.04 | 5.17 | 0.28 | 27.8 |
| July..... | Max..... | 83.29 | 75.18 | 84.93 | 76.08 | 85.44 | 75.63 | 85.43 | 74.62 | 85.54 | 73.98 | 78.94 | 71.83 | 83.0 |
| | Min..... | 70.74 | 72.87 | 71.76 | 74.31 | 71.67 | 73.70 | 72.19 | 73.31 | 72.02 | 73.10 | 74.08 | 71.54 | 58.5 |
| | Diff..... | 12.55 | 2.31 | 13.17 | 1.77 | 13.77 | 1.93 | 13.24 | 1.31 | 13.52 | 0.88 | 4.86 | 0.29 | 24.5 |
| August..... | Max..... | 81.53 | 74.08 | 83.14 | 75.18 | 83.57 | 74.76 | 83.29 | 73.77 | 83.30 | 73.29 | 77.30 | 71.93 | 81.1 |
| | Min..... | 68.50 | 71.73 | 69.49 | 73.36 | 69.43 | 72.73 | 70.05 | 72.49 | 69.74 | 72.32 | 72.72 | 71.53 | 57.6 |
| | Diff..... | 13.03 | 2.35 | 13.65 | 1.82 | 14.14 | 2.03 | 13.24 | 1.28 | 13.56 | 0.97 | 4.58 | 0.40 | 23.5 |
| **Seasonal...** | **Max.....** | **81.06** | **72.85** | **83.13** | **73.92** | **83.66** | **73.68** | **83.69** | **72.62** | **83.82** | **71.96** | **76.90** | **69.64** | **81.87** |
| | **Min.....** | **68.17** | **70.43** | **69.43** | **72.03** | **69.43** | **71.54** | **70.06** | **71.21** | **69.85** | **71.00** | **72.03** | **69.32** | **56.60** |
| | **Diff.....** | **12.89** | **2.42** | **13.70** | **1.89** | **14.23** | **2.14** | **13.63** | **1.41** | **13.97** | **0.96** | **4.87** | **0.32** | **25.27** |
| Autumn: | | | | | | | | | | | | | | |
| September.. | Max..... | 70.57 | 66.10 | 71.68 | 67.33 | 71.99 | 66.79 | 71.76 | 66.32 | 71.95 | 66.01 | 68.28 | 65.28 | 73.3 |
| | Min..... | 60.34 | 64.12 | 61.35 | 65.95 | 61.38 | 65.21 | 61.72 | 65.25 | 61.66 | 65.13 | 64.36 | 64.94 | 48.7 |
| | Diff..... | 10.23 | 1.98 | 10.33 | 1.38 | 10.61 | 1.58 | 10.04 | 1.07 | 10.29 | 0.88 | 3.92 | 0.34 | 24.6 |
| October.... | Max..... | 55.73 | 55.26 | 56.50 | 56.81 | 56.51 | 55.98 | 56.28 | 55.84 | 56.47 | 56.92 | 55.48 | 56.10 | 59.0 |
| | Min..... | 49.74 | 53.73 | 50.46 | 55.67 | 50.50 | 54.74 | 50.58 | 54.98 | 50.69 | 55.89 | 53.09 | 55.69 | 41.5 |
| | Diff..... | 5.99 | 1.53 | 6.04 | 1.14 | 6.01 | 1.24 | 5.70 | 0.86 | 5.78 | 1.03 | 2.39 | 0.41 | 17.5 |
| November.. | Max..... | 44.37 | 44.32 | 45.12 | 46.42 | 45.16 | 45.54 | 44.41 | 45.68 | 45.04 | 45.56 | 43.80 | 45.34 | 49.0 |
| | Min..... | 40.46 | 43.20 | 41.59 | 45.54 | 41.73 | 44.60 | 41.37 | 44.90 | 41.97 | 44.89 | 42.56 | 44.89 | 34.4 |
| | Diff..... | 3.91 | 1.12 | 3.53 | 0.88 | 3.43 | 0.94 | 3.04 | 0.78 | 3.07 | 0.67 | 1.24 | 0.45 | 14.6 |
| **Seasonal...** | **Max.....** | **56.89** | **55.23** | **57.77** | **56.85** | **57.89** | **56.10** | **57.48** | **55.95** | **57.82** | **56.16** | **55.85** | **55.57** | **60.43** |
| | **Min.....** | **50.18** | **53.68** | **51.13** | **55.72** | **51.20** | **54.85** | **51.22** | **55.04** | **51.44** | **55.30** | **53.34** | **55.17** | **41.53** |
| | **Diff.....** | **6.71** | **1.55** | **6.64** | **1.13** | **6.69** | **1.25** | **6.26** | **0.91** | **6.38** | **0.86** | **2.51** | **0.40** | **18.90** |
| **Yearly.....** | **Max.....** | **54.97** | **51.91** | **56.31** | **52.91** | **56.46** | **52.81** | **56.36** | **52.38** | **56.43** | **52.14** | **52.70** | **51.02** | **57.71** |
| | **Min.....** | **47.36** | **50.33** | **48.92** | **51.67** | **48.50** | **51.53** | **48.90** | **51.43** | **48.92** | **51.38** | **50.06** | **50.89** | **37.45** |
| | **ff.....** | **7.61** | **1.58** | **7.93** | **1.24** | **7.96** | **1.28** | **7.46** | **0.95** | **7.51** | **0.76** | **2.64** | **0.13** | **20.26** |

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TABLE 85.—MONTHLY, SEASONAL AND YEARLY MAXIMUM, MINIMUM AND AMPLITUDE OF TEMPERATURE OF SOILS WITH VARIOUS AMOUNTS OF ORGANIC MATTER.

| 1913–1914. | | 1.81% Org. Mat. | | 2.01% Org. Mat. | | 3.32% Org. Mat. | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Peat. | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | 5″ | 18″ | |
| Winter: | | | | | | | | | | | | | | |
| December.. | Max..... | 37.00 | 39.56 | 37.85 | 41.65 | 37.78 | 40.81 | 37.42 | 41.16 | 37.97 | 41.80 | 38.99 | 41.97 | 39.1 |
| | Min..... | 35.26 | 39.00 | 36.42 | 41.23 | 36.48 | 40.31 | 36.39 | 40.64 | 36.97 | 41.34 | 38.45 | 41.51 | 24.6 |
| | Diff..... | 1.74 | 0.56 | 1.43 | 0.42 | 1.30 | 0.50 | 1.03 | 0.52 | 1.00 | 0.46 | 0.54 | 0.46 | 14.5 |
| January.... | Max..... | 33.34 | 35.47 | 34.30 | 36.49 | 34.34 | 36.61 | 34.52 | 36.77 | 34.40 | 36.71 | 34.14 | 36.51 | 33.5. |
| | Min..... | 32.93 | 35.20 | 33.92 | 36.19 | 33.97 | 36.35 | 34.12 | 36.53 | 33.98 | 36.51 | 33.99 | 36.35 | 20.5 |
| | Diff..... | 0.41 | 0.27 | 0.38 | 0.30 | 0.37 | 0.26 | 0.40 | 0.24 | 0.42 | 0.20 | 0.15 | 0.16 | 13.0 |
| February... | Max..... | 32.43 | 35 10 | 33.52 | 36.02 | 33.81 | 36.28 | 34.22 | 36.56 | 34.51 | 36.67 | 34.64 | 36.47 | 23.5 |
| | Min..... | 32.06 | 34.83 | 33.22 | 35.73 | 33.50 | 35.97 | 33.91 | 36.26 | 34.24 | 36.37 | 34.35 | 36.19 | 1.9 |
| | Diff..... | 0.37 | 0.27 | 0.30 | 0.29 | 0.31 | 0.31 | 0.31 | 0.30 | 0.27 | 0.30 | 0.29 | 0.28 | 21.6 |
| **Seasonal...** | **Max.....** | **34.26** | **36.71** | **35.22** | **38.05** | **35.31** | **37.90** | **35.39** | **38.16** | **35.63** | **38.39** | **35.92** | **38.32** | **23.03** |
| | **Min.....** | **33.42** | **36.34** | **34.52** | **37.72** | **34.65** | **37.54** | **34.81** | **37.81** | **35.06** | **38.07** | **35.60** | **38.02** | **15.67** |
| | **Diff.....** | **0.84** | **0.37** | **0.70** | **0.33** | **0.66** | **0.36** | **0.58** | **0.35** | **0.57** | **0.32** | **0.32** | **0.30** | **16.36** |
| Spring: | | | | | | | | | | | | | | |
| March..... | Max..... | 37.00 | 36.50 | 37.96 | 37.03 | 37.91 | 37.37 | 38.04 | 37.48 | 37.87 | 37.35 | 34.99 | 35.98 | 39.7 |
| | Min..... | 33.70 | 35.77 | 35.20 | 36.49 | 35.20 | 36.76 | 35.56 | 37.03 | 35.63 | 36.97 | 34.55 | 35.74 | 22.5 |
| | Diff..... | 3.30 | 0.73 | 2.76 | 0.54 | 2.71 | 0.61 | 2.48 | 0.45 | 2.24 | 0.38 | 0.44 | 0.24 | 17.2 |
| April..... | Max..... | 51.13 | 46.07 | 51.68 | 45.77 | 51.79 | 45.63 | 50.77 | 45.32 | 50.23 | 44.87 | 46.61 | 42.92 | 55.2 |
| | Min..... | 42.11 | 44.00 | 43.33 | 44.35 | 43.28 | 44.54 | 43.73 | 44.36 | 43.87 | 44.14 | 44.22 | 42.56 | 34.2 |
| | Diff..... | 9.02 | 2.07 | 8.35 | 1.42 | 8.51 | 1.09 | 7.04 | 0.96 | 6.36 | 0.73 | 2.39 | 0.36 | 21.0 |
| May ..... | Max..... | 67.53 | 58.80 | 68.68 | 58.30 | 68.63 | 58.77 | 68.27 | 57.77 | 68.08 | 57.07 | 61.81 | 54.75 | 70.6 |
| | Min..... | 53.68 | 55.92 | 54.71 | 56.09 | 54.53 | 56.38 | 54.92 | 56.12 | 54.96 | 55.93 | 57.32 | 54.37 | 46.5 |
| | Diff..... | 13.85 | 2.88 | 13.97 | 2.21 | 14.10 | 1.39 | 13.35 | 1.65 | 13.12 | 1.14 | 4.49 | 0.38 | 24.1 |
| **Seasonal...** | **Max.....** | **51.89** | **47.12** | **52.77** | **47.03** | **52.78** | **47.26** | **52.36** | **46.86** | **52.06** | **46.43** | **47.80** | **44.55** | **55.17** |
| | **Min.....** | **43.16** | **45.23** | **44.41** | **45.64** | **44.34** | **45.89** | **44.74** | **45.80** | **44.82** | **45.68** | **45.36** | **44.22** | **34.40** |
| | **Diff.....** | **8.73** | **1.89** | **8.36** | **1.39** | **8.34** | **1.37** | **7.62** | **1.06** | **7.24** | **0.75** | **2.44** | **0.33** | **20.77** |
| Summer: | | | | | | | | | | | | | | |
| June ..... | Max..... | 76.45 | 68.78 | 80.37 | 69.50 | 80.65 | 70.21 | 81.01 | 69.42 | 81.11 | 68.88 | 74.72 | 66.71 | 77.6 |
| | Min..... | 64.12 | 66.32 | 66.33 | 67.33 | 66.23 | 67.83 | 66.67 | 67.67 | 66.79 | 67.60 | 69.74 | 66.24 | 54.3 |
| | Diff..... | 12.33 | 2.46 | 14.04 | 2.17 | 14.42 | 2.38 | 14.34 | 1.75 | 14.32 | 1.28 | 4.98 | 0.47 | 23.2 |
| July..... | Max..... | 81.73 | 73.80 | 84.06 | 73.70 | 84.13 | 74.36 | 84.72 | 73.60 | 84.92 | 73.02 | 78.81 | 70.84 | 83.0 |
| | Min..... | 69.36 | 71.06 | 70.95 | 71.48 | 70.66 | 71.93 | 71.17 | 71.76 | 71.63 | 71.77 | 74.01 | 70.55 | 59.0 |
| | Diff..... | 12.37 | 2.74 | 13.11 | 2.22 | 13.47 | 2.43 | 13.55 | 1.84 | 13.29 | 1.25 | 4.80 | 0.29 | 24.0 |
| August..... | Max..... | 77.76 | 72.24 | 80.65 | 72.17 | 79.83 | 72.89 | 79.60 | 72.21 | 79.68 | 72.02 | 75.63 | 70.95 | 81.0 |
| | Min..... | 66.54 | 69.96 | 68.66 | 70.74 | 68.01 | 70.98 | 68.33 | 70.88 | 68.50 | 71.06 | 71.65 | 70.61 | 57.0 |
| | Diff ..... | 11.22 | 2.28 | 11.99 | 1.43 | 11.82 | 1.91 | 11.27 | 1.33 | 11.18 | 0.96 | 3.98 | 0.34 | 24.0 |
| **Seasonal...** | **Max.....** | **78.65** | **71.61** | **81.69** | **71.79** | **81.54** | **72.49** | **81.78** | **71.74** | **81.90** | **71.31** | **76.39** | **69.50** | **80.53** |
| | **Min.....** | **66.67** | **69.11** | **68.65** | **69.85** | **68.30** | **70.25** | **68.72** | **70.10** | **68.97** | **70.14** | **71.20** | **69.13** | **56.77** |
| | **Diff.....** | **11.98** | **2.50** | **13.04** | **1.94** | **13.24** | **2.24** | **13.06** | **1.64** | **12.93** | **1.17** | **4.59** | **0.37** | **23.76** |
| Autumn: | | | | | | | | | | | | | | |
| September.. | Max..... | 68.24 | 64.74 | 70.26 | 65.02 | 69.91 | 65.33 | 70.10 | 64.98 | 70.11 | 64.97 | 66.36 | 64.18 | 72.0 |
| | Min..... | 57.34 | 62.38 | 59.22 | 63.28 | 58.71 | 63.47 | 59.21 | 63.68 | 59.34 | 64.02 | 62.92 | 63.76 | 48.0 |
| | Diff..... | 10.90 | 2.36 | 11.04 | 1.74 | 11.20 | 1.86 | 10.89 | 1.30 | 10.77 | 0.95 | 3.44 | 0.42 | 24.0 |
| October.... | Max..... | 59.17 | 57.55 | 60.42 | 57.91 | 59.94 | 58.18 | 60.22 | 58.22 | 60.33 | 58.37 | 58.19 | 58.10 | 65.0 |
| | Min..... | 51.12 | 55.62 | 52.67 | 56.64 | 52.54 | 56.69 | 52.96 | 57.22 | 53.21 | 57.48 | 55.61 | 57.69 | 44.0 |
| | Diff..... | 8.05 | 1.93 | 7.75 | 1.27 | 7.40 | 1.49 | 7.26 | 1.00 | 7.12 | 0.89 | 2.58 | 0.41 | 21.0 |
| November.. | Max..... | 40.34 | 42.86 | 41.76 | 43.72 | 41.76 | 43.94 | 41.94 | 44.25 | 41.96 | 44.72 | 41.81 | 44.89 | 47.0 |
| | Min ..... | 37.13 | 41.52 | 38 67 | 42.80 | 38.61 | 43.03 | 38.98 | 43.54 | 39.14 | 44.10 | 40.52 | 44.55 | 28.0 |
| | Diff..... | 3.21 | 1.34 | 3.09 | 0.92 | 3.15 | 0.91 | 2.96 | 0.71 | 2.82 | 0.62 | 1.29 | 0.34 | 19.0 |
| **Seasonal...** | **Max.....** | **55.92** | **55.05** | **57.48** | **55.55** | **57.20** | **55.82** | **57.42** | **55.82** | **57.47** | **56.02** | **55.45** | **55.72** | **61.33** |
| | **Min.....** | **48.53** | **53.17** | **50.19** | **54.24** | **49.95** | **54.40** | **50.38** | **54.81** | **50.56** | **55.20** | **53.02** | **55.33** | **40.00** |
| | **Diff.....** | **7.39** | **1.88** | **7.29** | **1.31** | **7.25** | **1.42** | **7.04** | **1.01** | **6.91** | **0.82** | **2.43** | **0.39** | **21.33** |
| **Yearly.....** | **Max.....** | **55.18** | **52.62** | **56.79** | **53.11** | **56.71** | **53.37** | **56.74** | **53.15** | **56.77** | **53.04** | **53.89** | **52.02** | **58.27** |
| | **Min.....** | **47.95** | **50.96** | **49.44** | **51.86** | **49.31** | **52.02** | **49.66** | **52.13** | **49.85** | **52.27** | **51.45** | **51.68** | **36.71** |
| | **Diff.....** | **7.23** | **1.66** | **7.35** | **1.25** | **7.40** | **1.35** | **7.08** | **1.02** | **6.92** | **0.77** | **2.44** | **0.34** | **21.56** |

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TABLE 86.—MONTHLY, SEASONAL, AND YEARLY MAXIMUM, MINIMUM AND AMPLITUDE OF TEMPERATURE OF SOILS WITH VARIOUS AMOUNTS OF ORGANIC MATTER.

| 1914–1915. | | 1.81% Org. Mat. | | 2.01% Org. Mat. | | 3.32% Org. Mat. | | 5.47% Org. Mat. | | 6.95% Org. Mat. | | Peat. | | Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3″ | 6″ | 3″ | 6″ | 3″ | 6″ | 3″ | 6″ | 3″ | 6″ | 3″ | 6″ | |
| Winter: | | | | | | | | | | | | | | |
| December | Max | 32.21 | 33.69 | 33.44 | 34.30 | 33.69 | 34.79 | 33.97 | 34.70 | 34 44 | 35.20 | 35.03 | 35.71 | 28 0 |
| | Min | 30.44 | 32.98 | 31.53 | 33.67 | 32.38 | 34.25 | 32.95 | 34.30 | 33.83 | 34.91 | 34.69 | 35.45 | 15 0 |
| | Diff | 1.77 | 0.71 | 1.91 | 0.63 | 1.31 | 0.54 | 1.02 | 0.40 | 0.61 | 0.29 | 0.34 | 0.26 | 13.0 |
| January | Max | 30.62 | 31.65 | 31.78 | 32.63 | 32.39 | 33.34 | 32.77 | 33.34 | 32.97 | 33.54 | 32.89 | 32.88 | 28.0 |
| | Min | 29.98 | 31.32 | 31.37 | 32.39 | 32.02 | 33.14 | 32.49 | 33.20 | 32.79 | 33.40 | 32.70 | 32.70 | 12.9 |
| | Diff | 0.64 | 0.33 | 0.41 | 0.24 | 0.37 | 0.20 | 0.28 | 0.14 | 0.18 | 0.14 | 0.11 | 0.18 | 15.1 |
| February | Max | 32.46 | 33.05 | 33.46 | 33.73 | 33.45 | 34.06 | 33.72 | 33.91 | 33.61 | 33.91 | 32.76 | 32 41 | 36.2 |
| | Min | 30.75 | 32.33 | 32.23 | 33.31 | 32.66 | 33.66 | 32.70 | 33.36 | 32.93 | 33.45 | 32.48 | 32.30 | 22.5 |
| | Diff | 1.71 | 0.72 | 1.23 | 0.42 | 0.79 | 0.40 | 1.02 | 0.55 | 0.68 | 0.46 | 0.28 | 0.11 | 13.7 |
| **Seasonal** | **Max** | **31.76** | **32.80** | **32.89** | **33.55** | **33.18** | **34.06** | **33.49** | **33.98** | **33.67** | **34.22** | **33.56** | **33.67** | **30.73** |
| | **Min** | **30.39** | **32.21** | **31.71** | **33.12** | **32.35** | **33.68** | **32.71** | **33.62** | **33.18** | **33.92** | **33.29** | **33.48** | **16.80** |
| | **Diff** | **1.37** | **0.59** | **1.18** | **0.43** | **0.83** | **0.38** | **0.78** | **0.36** | **0.49** | **0.30** | **0.27** | **0.19** | **13.93** |
| Spring: | | | | | | | | | | | | | | |
| March | Max | 36.71 | 36.98 | 37.81 | 37.48 | 37.40 | 37.48 | 37.04 | 36.79 | 37.02 | 36.88 | 32.76 | 32.32 | 39.6 |
| | Min | 30.52 | 33.01 | 31.71 | 33.63 | 32.21 | 33.95 | 32.86 | 34.06 | 33.26 | 34.49 | 32.38 | 32.15 | 20.6 |
| | Diff | 6 19 | 3.97 | 6.10 | 3.85 | 5.19 | 3.53 | 4.18 | 2.73 | 3.76 | 2.39 | 0.38 | 0.17 | 19.0 |
| April | Max | 60.69 | 57.83 | 63.15 | 58.53 | 62.28 | 58.89 | 61.20 | 57.74 | 60.32 | 56.67 | 52.52 | 46.66 | 63.0 |
| | Min | 45.64 | 47.08 | 46.41 | 47.57 | 46.35 | 47.74 | 46.82 | 47.80 | 46.73 | 48.56 | 45.64 | 45.23 | 40 1 |
| | Diff | 15.05 | 10.75 | 16.74 | 10.96 | 15.93 | 11.15 | 14.38 | 9.94 | 13.59 | 8.11 | 6.88 | 1.43 | 22.9 |
| May | Max | 62.09 | 60.32 | 66.09 | 62.46 | 64.99 | 62.22 | 64.14 | 61.22 | 63.79 | 61.06 | 60.05 | 54.56 | 62.3 |
| | Min | 47.98 | 50.27 | 49.07 | 50.96 | 48.86 | 50.91 | 49.58 | 51.10 | 49.53 | 52.38 | 51.38 | 52.90 | 40.7 |
| | Diff | 14.11 | 10.05 | 17.02 | 11.50 | 16.13 | 11.31 | 14.56 | 10.12 | 14.26 | 8.68 | 8.67 | 1.66 | 21.6 |
| **Seasonal** | **Max** | **53.16** | **51.71** | **55.68** | **52.82** | **54.89** | **52.86** | **54.13** | **51.92** | **53.71** | **51.54** | **48.44** | **44.51** | **54.97** |
| | **Min** | **41.38** | **43.45** | **42.40** | **44.05** | **42.47** | **44.20** | **43.09** | **44.32** | **42.84** | **45.14** | **43.13** | **43.43** | **33.80** |
| | **Diff** | **11.78** | **8.26** | **13.28** | **8.77** | **12.42** | **8.66** | **11.04** | **7.60** | **10.87** | **6.40** | **5.31** | **1.08** | **21.17** |
| Summer: | | | | | | | | | | | | | | |
| June | Max | 74.71 | 71.20 | 77.71 | 72.78 | 76.90 | 73.06 | 75.92 | 72.00 | 75.99 | 71.11 | 71.09 | 63.51 | 72 7 |
| | Min | 56 62 | 58.88 | 57.55 | 59.42 | 57.36 | 59.33 | 57.92 | 59.59 | 57.90 | 60.12 | 59.62 | 61.36 | 49.3 |
| | Diff | 18.09 | 12.32 | 20.16 | 13.36 | 18.54 | 13.73 | 18.00 | 12.41 | 18.09 | 10.99 | 11.47 | 2.15 | 23.4 |
| July | Max | 79.19 | 76 45 | 83 73 | 78.79 | 82.60 | 78.99 | 82.26 | 78.21 | 81.77 | 76.96 | 77.77 | 70.15 | 77.9 |
| | Min | 62.90 | 65.02 | 64.37 | 65.87 | 64.21 | 65.84 | 64.63 | 65.82 | 64.66 | 66.36 | 65.77 | 67 82 | 57.9 |
| | Diff | 16.29 | 11 43 | 19.36 | 12.92 | 18.39 | 13.15 | 17.63 | 12.39 | 17.11 | 10.60 | 12.00 | 2.33 | 20.0 |
| Aug | Max | 74 80 | 72.82 | 78.14 | 74.22 | 77.16 | 74.72 | 76.87 | 73.86 | 76.37 | 72.90 | 73.28 | 67.57 | 73 3 |
| | Min | 59.93 | 62.87 | 61.24 | 63.47 | 61.15 | 63.72 | 61.81 | 63.71 | 61.71 | 64.29 | 63.48 | 65.76 | 53.6 |
| | Diff | 14 87 | 9.95 | 16.90 | 10.75 | 16.01 | 11.00 | 15.06 | 10.15 | 14.66 | 8.61 | 9.80 | 1.81 | 19.7 |
| **Seasonal** | **Max** | **76.23** | **73.49** | **79.86** | **75.26** | **78.89** | **75.59** | **78.35** | **74.69** | **78.04** | **73.66** | **74.05** | **67.08** | **74.63** |
| | **Min** | **59.82** | **62.26** | **61.05** | **62.92** | **60.91** | **62.96** | **61.45** | **63.04** | **61.42** | **63.59** | **62.96** | **64.98** | **53.60** |
| | **Diff** | **16.41** | **11.23** | **18.81** | **12.34** | **17.98** | **12.63** | **16.90** | **11.65** | **16.62** | **10.07** | **11.09** | **2.10** | **21.03** |
| Autumn: | | | | | | | | | | | | | | |
| September | Max | 73.16 | 70.24 | 75.98 | 71.49 | 74.93 | 71.81 | 74.40 | 71.05 | 73.64 | 70.02 | 70.21 | 64.52 | 73.8 |
| | Min | 57 12 | 59.80 | 58.05 | 60.21 | 58.04 | 60.45 | 58.92 | 60.60 | 58.80 | 61.28 | 60.54 | 62.58 | 52.6 |
| | Diff | 16.04 | 10.44 | 17.93 | 11.28 | 16.89 | 11.36 | 15.48 | 10.45 | 14.84 | 8.74 | 9.67 | 1.94 | 21.2 |
| October | Max | 57.63 | 56.00 | 59.92 | 56.90 | 59.11 | 57.57 | 59.28 | 57.13 | 58.53 | 56.66 | 55.92 | 52.16 | 61.2 |
| | Min | 46.48 | 48.65 | 47 52 | 48.92 | 47.42 | 49.30 | 48.26 | 49.38 | 47.99 | 49.84 | 48.82 | 50.27 | 41.0 |
| | Diff | 11.15 | 7.35 | 12.40 | 7.98 | 11.69 | 8.27 | 11.02 | 7.75 | 10.54 | 6.82 | 7.10 | 1.89 | 20.2 |
| November | Max | 43.50 | 43.55 | 45.43 | 44.18 | 44.84 | 44.62 | 45.05 | 44.46 | 44.79 | 44.38 | 43.38 | 42.71 | 47.4 |
| | Min | 37.39 | 39.97 | 38.69 | 40.44 | 38.72 | 40.77 | 39.47 | 40.94 | 39.55 | 41.40 | 40.55 | 41.81 | 32.1 |
| | Diff | 6.11 | 3.58 | 6.74 | 3.74 | 6.12 | 3.85 | 5.58 | 3.52 | 5.24 | 2.98 | 2.83 | 0.90 | 15.3 |
| **Seasonal** | **Max** | **58.10** | **56.60** | **60.44** | **57.52** | **59.63** | **58.00** | **59.58** | **57.55** | **58.99** | **57.02** | **56.50** | **53.13** | **60.80** |
| | **Min** | **47.00** | **49.47** | **48.09** | **49.88** | **48.06** | **50.17** | **48.88** | **50.31** | **48.78** | **50.84** | **49.97** | **51.55** | **41.90** |
| | **Diff** | **11.10** | **7.13** | **12.35** | **7.66** | **11.57** | **7.83** | **10.70** | **7.24** | **10.21** | **6.18** | **6.53** | **1.58** | **18.90** |
| **Yearly** | **Max** | **54.81** | **53.65** | **57.22** | **54.79** | **56.65** | **55.13** | **56.39** | **54.54** | **56.10** | **54.11** | **53.14** | **49.60** | **55.28** |
| | **Min** | **44.65** | **46.85** | **45.81** | **47.49** | **45.95** | **47.75** | **46.53** | **47.82** | **46.56** | **48.37** | **47.34** | **48.36** | **36.53** |
| | **Diff** | **10.16** | **6.80** | **11.41** | **7.30** | **10.70** | **7.38** | **9.86** | **6.72** | **9.54** | **5.74** | **5.80** | **1.24** | **18.75** |

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The chief and most important facts revealed by the preceding tables may be summarized as follows: (1) The magnitude of the fluctuation was very small in winter in all soils and at all depths. After the soils thawed, however, it began to increase until it reached a maximum in June and July and then commenced to decrease again until winter. (2) At the 18-inch depth the degree of amplitude was very small throughout the year in all soils but especially in peat. At the 3, 5 and 6-inch depths, however, it was very high and about the same during the summer months in all the soils having various percentages of organic matter, but quite lower in peat. (3) The minimum temperature attained was highest in peat, slightly less and about the same in the various soils treated with peat, and lowest in the untreated sand. While the maximum was greatest and practically equal in the treated soils, slightly smaller in the untreated sand, and still smaller in peat, the variations, both for the minimum and maximum were not very large. (4) The amplitude of the air temperature was considerably higher than that of all soils at any depth.

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## ADDITIONAL EXPERIMENTAL DATA ON THE TEMPERATURE OF CULTIVATED, UNCULTIVATED AND SOD SOIL.

### PLAN OF THE EXPERIMENT.

A correct knowledge of the effect of cultural methods, such as cultivation, uncultivation and sod, upon the soil temperature is of great interest and importance both from the scientific as well as from the practical standpoint. The current information concerning the effect of these cultural methods upon soil temperature is limited and unsatisfactory. Consequently, in November, 1911, at the time that the foregoing series of experiments were started, a systematic and thorough investigation of this problem was also instituted. The research consisted of measuring the temperature of soil under the above conditions by means of thermographs[5]. It was thought and hoped that by the use of such instruments, which make continuous records, very definite and extremely important information would be procured upon the subject. Unfortunately, however, these instruments proved to be a failure, as the bulbs containing the liquid medium would always leak in spite of many precautionary measures taken and the numerous repairs made. It seems that the joints between the tube and the hollow wire would corrode in the soil and allow the liquid to escape. After employing these instruments, seven in number, three double and two single, for two years they were abandoned because the data obtained by them could not be relied upon. They were replaced, however, by soil mercury thermometers graduated to 0.5°F. Only two years' data have been secured by the latter instruments. During the year 1913 the temperature was measured at 7-inch depth, three times a day as usual. During 1915, however, it was recorded at 3 and 6-inch depths. In Table 87 are presented the monthly maximum, minimum, amplitude and average temperature of the soil under the various cultural conditions during the two years.

It should be stated that the uncultivated plot was kept undistributed but free of weeds; the cultivated plot was stirred almost always after a rain; the vegetation of the sod land consisted of alfalfa and grass and was never cut throughout the four years.

[5]Obtained from Frietz, Baltimore, Md.

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TABLE 87.—MAXIMUM, MINIMUM, AMPLITUDE AND AVERAGE TEMPERATURE OF UNCULTIVATED, CULTIVATED AND SOD SOIL.

| 1913. | | April. | | | | May. | | | | June. | | | | July. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| Uncultivated | 7″ | 49.17 | 41.39 | 7.78 | 45.73 | 60.14 | 51.85 | 8.29 | 56.48 | 73.39 | 62.81 | 10.48 | 68.61 | 80.36 | 69.49 | 10.87 | 75.12 |
| Cultivated | 7″ | 47.80 | 41.80 | 6.00 | 44.96 | 59.62 | 53.23 | 6.39 | 56.51 | 72.81 | 64.38 | 7.43 | 68.58 | 77.84 | 70.22 | 7.62 | 73.91 |
| Sod | 7″ | 46.55 | 43.10 | 3.45 | 44.81 | 55.62 | 52.52 | 3.10 | 54.16 | 62.82 | 59.49 | 3.33 | 61.62 | 68.38 | 65.51 | 2.87 | 66.92 |

| 1913. | | August. | | | | September. | | | | October. | | | | November. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| Uncultivated | 7″ | 77.49 | 67.84 | 9.65 | 72.80 | 66.87 | 59.99 | 6.88 | 63.67 | 53.58 | 49.58 | 4.00 | 51.72 | 42.27 | 39.74 | 2.53 | 41.11 |
| Cultivated | 7″ | 75.82 | 67.48 | 8.34 | 71.78 | 66.50 | 60.37 | 6.13 | 63.46 | 53.86 | 49.94 | 3.82 | 52.03 | 43.25 | 40.59 | 2.66 | 41.84 |
| Sod | 7″ | 68.49 | 66.04 | 2.45 | 67.26 | 60.42 | 58.53 | 1.89 | 59.50 | 52.78 | 51.31 | 1.47 | 52.06 | 43.15 | 41.77 | 1.38 | 42.46 |

| 1914-1915. | | December. | | | | January. | | | | February. | | | | March. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max | Min. | Diff. | Ave. |
| Uncultivated | 3″ | 33.09 | 31.92 | 1.17 | 32.53 | 31.51 | 31.11 | 0.40 | 31.30 | 31.83 | 30.70 | 1.13 | 31.34 | 34.83 | 31 29 | 3.54 | 33.23 |
| Cultivated | 3″ | 33.96 | 33.26 | 0.70 | 33.64 | 32.91 | 32.59 | 0.32 | 32.75 | 33.35 | 32.49 | 0.86 | 32.97 | 34.67 | 32.11 | 2.56 | 33.52 |
| Sod | 3″ | 35.59 | 35.34 | 0.25 | 35.46 | 34.82 | 34.55 | 0.27 | 34.70 | 33.85 | 33.52 | 0.33 | 33.69 | 33.48 | 32.78 | 0.70 | 33.15 |

| | | April. | | | | May. | | | | June. | | | | July. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| Uncultivated | 3″ | 58.66 | 44.90 | 13.76 | 53.34 | 61.42 | 48.79 | 12.63 | 56.68 | 72.32 | 56.93 | 15.40 | 66.55 | 78.41 | 64.07 | 14.34 | 73.07 |
| Uncultivated | 6″ | ..... | ..... | ..... | ..... | 60.38 | 50.53 | 9.85 | 56.45 | 70.56 | 59.12 | 11.44 | 65.90 | 76.62 | 66.03 | 10.59 | 72.32 |
| Cultivated | 3″ | 56.38 | 45.55 | 10.83 | 52.15 | 59.34 | 49.42 | 9.92 | 55.91 | 69.53 | 57.40 | 12.13 | 64.94 | 75.78 | 64.20 | 11.58 | 71.33 |
| Cultivated | 6″ | ..... | ..... | ..... | ..... | 58.53 | 51.92 | 6.61 | 55.64 | 67.84 | 59.60 | 8.24 | 64.38 | 73.86 | 66.19 | 7.67 | 70.66 |
| Sod | 3″ | 49.48 | 44.81 | 4.67 | 47.41 | 53.88 | 50.37 | 3.51 | 52.42 | 61.13 | 57.05 | 4.08 | 59.56 | 69.40 | 64.08 | 5.32 | 67.44 |
| Sod | 6″ | ..... | ..... | ..... | ..... | 53.07 | 50.96 | 2.11 | 52.13 | 60.04 | 57.97 | 2.07 | 59.07 | 67.62 | 64.67 | 2.95 | 66.24 |

| | | August. | | | | September. | | | | October | | | | November. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| Uncultivated | 3″ | 73.12 | 60.63 | 12.49 | 68.52 | 70.44 | 58.00 | 12.44 | 65.57 | 55.88 | 47.23 | 8.65 | 52.26 | 42.90 | 38.02 | 4.88 | 40.70 |
| Uncultiavted | 6″ | 72.34 | 63.43 | 8.91 | 68.81 | 69.18 | 60.74 | 8.44 | 65.81 | 54.90 | 49.28 | 5.62 | 52.73 | 42.91 | 40.19 | 2.72 | 41.78 |
| Cultivated | 3″ | 72.12 | 61.49 | 10.63 | 68.15 | 69.41 | 58.62 | 10.79 | 65.26 | 54.68 | 48.10 | 6.58 | 52.20 | 42.89 | 39.03 | 3.86 | 41.26 |
| Cultivated | 6″ | 70.73 | 64.08 | 6.65 | 67.84 | 67.91 | 61.12 | 6.79 | 65.09 | 54.52 | 50.07 | 4.45 | 52.60 | 43.37 | 41.05 | 2.32 | 42.35 |
| Sod | 3″ | 67.07 | 62.52 | 4.55 | 65.34 | 64.67 | 60.17 | 4.50 | 62.92 | 53.22 | 50.38 | 2.84 | 52.11 | 43.70 | 41.71 | 1.99 | 42.84 |
| Sod | 6″ | 65.82 | 63.92 | 1.90 | 64.97 | 63.24 | 61.32 | 1.92 | 62.36 | 53.01 | 51.53 | 1.48 | 52.32 | 44.18 | 43.10 | 1.08 | 43.62 |

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Table 87 shows (1) that the average temperature of the sod soil at 7 inches depth was about the same or only slightly lower than that of the cultivated and uncultivated, during the month of April. From this month on, the sod plot began to have decidely lower temperature than the other plots and continued to be colder until October. The highest variation occurred in June and July when the average temperature of the sod land was about 6 or 7°F lower than that of the bare land. These differences, however, commenced to become smaller in August and by September they had practically disappeared. In October the order of magnitude was reversed, the sod plot became warmer than the other two plots and continued to have a higher temperature until freezing and even during the winter months. The data for the winter months for this year are not included in the above table on account of incompleteness but they are on file and show that as a monthly average the temperature of the sod plot remained about 2°F higher than that of the cultivated and uncultivated plots.

(2) During the months of April, May and June the average temperature of the uncultivated and cultivated soil was practically equal. During July and August, however, the uncultivated plot was about 1°F warmer than the cultivated, but during September, October, and November and also during the winter months they had again equal temperature.

(3) The degree of amplitude was highest in the uncultivated plot, slightly smaller in the cultivated, and very small in the sod. Thus, for instance, in July it amounted to 10.87° in the uncultivated plot, 7.62° in the cultivated, and only 2.87°F in the sod.

(4) As a rule the uncultivated plot had a slightly higher maximum temperature than the cultivated, but the latter kept a slightly higher minimum than the former. The magnitude of the maximum and minimum of the sod plot was practically equal to that of the other plots in the early spring and fall; in the summer it was far below, but in the winter somewhat higher.

Table 87 contains also the monthly maximum, minimum, amplitude and average temperature of the same plots during the year of 1915 but at different depths—3 and 6 inches. The data in this table reveal exactly the same principles as the preceding and consequently need no further discussion.

The daily march of temperature which is not included here on account of lack of space, indicates (1) that in the spring all the three plots thawed practically simultaneously, (2) The temperature of the cultivated and uncultivated plots would rise quicker and higher whenever the air temperature rose very rapidly and suddenly than that of the sod. The converse of this was also true. (3) As between the cultivated and uncultivated the rate of rising and falling of temperature was somewhat similar to that of the sod, but to less degree, of course.

Tihs investigation, therefore, proves two very important facts. (1) A soil with compacted or undisturbed surface is only slightly warmer, about 1°F, than a cultivated soil, and that is only in the summer months and possibly in the spring; in the fall and winter months both soils are equally warm. (2) A soil covered with a growing or dead vegetation has a slightly lower temperature in the spring, considerably lower in the summer, but slightly higher in the fall and appreciably higher in the winter than the bare soils. The vegetation cover, therefore, has both a

cooling and warming effect upon the soil in opposite direction to the air temperature of the season.

The slightly higher temperature of the uncultivated soil over the cultivated during the summer and possibly in the spring, is due chiefly to the dry mulch formed on the cultivated soil. This dry mulch forms rather poor and imperfect connections with the lower layers of the soil and the heat energy which it receives from the sun is not all conducted downward rapidly but a large amount of it is allowed to accumulate on the surface of this mulch and then some of it is radiated back to the atmosphere, while on account of the compacted condition and consequently better heat conducting power a greater amount of heat is propogated to the lower depths in the case of the uncultivated soil and not so much accumulates at the surface and then radiated into space. These facts were experimentally proved by the following series of experiments. The bulbs of mercury thermometers were placed one inch above the surface of both the cultivated and uncultivated soils. It was found that the thermometer over the cultivated soil would register at certain days about 10°F higher temperature than that placed over the uncultivated soil. In another experiment the bulbs of the thermometers were placed horizontally over the surface of both soils. It was discovered also in this case that the surface of the cultivated soil would be 7 or 8°F warmer in certain days than that of the uncultivated.

This same mulch, however, for the same reason that it reduces somewhat the amount of heat penetrating the lower depths during the insolation, diminishes equally well the quantity of heat that is lost during the night.

The dry mulch then tends to act as a blanket analogous to that of vegetation cover, but to a less degree. It is perhaps due to this mulch and also to the slightly higher moisture content that the temperature of the cultivated soil rises or falls somewhat less rapidly than that of the uncultivated.

The cooling and warming effect of the cover crop in both the warm and cold seasons of the year is self-evident. In the summer time the growing crop keeps the soil temperature low for the following reasons: (1) Practically all the sun rays are intercepted by the growing vegetation so that the surface ground is nearly all shaded and its temperature rise is dependent upon the wind and convection currents and conduction, and not upon any direct heat absorption. (2) The air temperature around the plants and at the surface of the soil is low on account of the great amount of transpiration and some evaporation that take place. Both of these processes have, of course, a tremendous influence upon the soil temperature.

In the cold part of the year the dead or partially decayed vegetation acts as a blanket over the surface soil. This cover performs several functions chief which are: (1) The prevention of the cold currents of air from coming in contact with the surface soil and thereby cooling it, and (2) the layer of vegetation is porous and the spaces are filled with air. This air being a very poor conductor of heat does not transmit very rapidly heat from the soil to the air above and vice versa and as a result the soil loses its heat less rapidly than if it were unprotected.

It is through the vegetation cover that is afforded probably one of the most efficient and expedient means of preventing extreme low soil tem-

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perature in the winter which would be detrimental to vegetation. A vegetation cover coupled with snow certainly forms a very powerful soil temperature protector.

## EFFECT OF SNOW ON THE SOIL TEMPERATURE.

From the theoretical standpoint a layer of snow ought to protect the soil against very severe cold weather and keep its temperature higher and steadier. Its effect would seem to be analogous to that of a vegetation cover. It ought to act as a blanket and reduce the rapid loss of heat firstly by preventing the convection and wind currents from coming in contact with the surface soil, and secondly, on account of its poor heat conductivity.

When the thickness of the layer is rather large, snow is certainly a most efficient agent in protecting the soil from very low temperature. Observations have been made upon the subject through four successive winters and the results obtained are exceedingly interesting and of great practical importance. Some of these results have already been published in the previous report. In the present paper will be presented only the data collected during the month of January 1915. The observations conducted during this year consisted of noting the temperature of soil at 3 inches deep under the following conditions: (1) bare, (2) covered with compacted snow, (3) covered with uncompacted snow, and (4) covered with layer of vegetation and uncompacted snow. Table 88 contains the daily and monthly maximum, minimum, amplitude, and average temperature for the month of January.

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TABLE 88.—EFFECT OF SNOW COVER ON SOIL TEMPERATURE, JANUARY, 1915.

| | Daily Maximum-Minimum. | | | | | Daily Average. | | | | Air. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bare. | Compacted. | Uncompacted. | Uncompacted and vegetation. | | Bare. | Compacted. | Uncompacted. | Uncompacted and vegetation. | Maximum. | Minimum. | Average. |
| 2 Max | 29.8 | 30.9 | 31.7 | 35.4 | 2.... | 29.60 | 30.80 | 31.60 | 35.30 | 26 | 1 | 14 |
| 2 Min | 29.3 | 30.7 | 31.5 | 35.2 | | | | | | | | |
| 4 Max | 29.0 | 30.2 | 31.8 | 35.5 | 4.... | 27.37 | 29.73 | 31.67 | 35.37 | 33 | 17 | 25 |
| 4 Min | 24.2 | 29.1 | 31.5 | 35.3 | | | | | | | | |
| 5 Max | 31.9 | 31.4 | 32.0 | 35.7 | 5.... | 30.60 | 31.20 | 31.87 | 35.93 | 41 | 27 | 34 |
| 5 Min | 28.8 | 30.8 | 31.7 | 35.4 | | | | | | | | |
| 6 Max | 32.3 | 32.0 | 32.0 | 35.7 | 6.... | 32.20 | 31.93 | 32.00 | 35.63 | 39 | 33 | 36 |
| 6 Min | 32.1 | 31.8 | 32.0 | 35.5 | | | | | | | | |
| 7 Max | 32.3 | 32.3 | 32.0 | 35.3 | | | | | | | | |
| 7 Min | 31.3 | 32.3 | 32.0 | 35.2 | 7.... | 31.83 | 32.30 | 32.00 | 35.27 | 34 | 21 | 28 |
| 8 Max | 29.5 | 32.3 | 32.1 | 35.4 | | | | | | | | |
| 8 Min | 27.5 | 32.1 | 32.0 | 35.2 | 8.... | 28.70 | 32.20 | 32.03 | 35.30 | 26 | 19 | 22 |
| 9 Max | 28.6 | 31.5 | 32.0 | 35.4 | | | | | | | | |
| 9 Min | 24.8 | 31.2 | 31.8 | 35.1 | 9.... | 27.07 | 31.30 | 31.87 | 35.27 | 23 | 15 | 19 |
| 11 Max | 31.8 | 31.9 | 32.2 | 35.5 | | | | | | | | |
| 11 Min | 29.7 | 31.2 | 32.0 | 35.4 | 11.... | 30.90 | 31.63 | 32.07 | 35.43 | 36 | 30 | 33 |
| 12 Max | 31.4 | 32.0 | 32.0 | 35.4 | | | | | | | | |
| 12 Min | 30.8 | 3.18 | 31.9 | 35.2 | 12.... | 31.03 | 31.87 | 31.97 | 35.30 | 33 | 27 | 30 |
| 13 Max | 30.9 | 31.6 | 32.0 | 35.3 | | | | | | | | |
| 13 Min | 28.4 | 31.0 | 31.8 | 35.2 | 13.... | 30.03 | 31.33 | 31.93 | 35.27 | 33 | 22 | 28 |
| 14 Max | 31.8 | 31.8 | 32.1 | 35.6 | | | | | | | | |
| 14 Min | 28.2 | 31.0 | 31.9 | 35.2 | 14.... | 30.47 | 31.53 | 32.00 | 35.40 | 36 | 27 | 32 |
| 15 Max | 31.9 | 31.9 | 32.3 | 35.5 | | | | | | | | |
| 15 Min | 28.8 | 31.1 | 31.9 | 35.2 | 15.... | 30.77 | 31.63 | 32.07 | 35.37 | 35 | 25 | 30 |
| 16 Max | 32.0 | 32.1 | 32.2 | 35.3 | | | | | | | | |
| 16 Min | 28.9 | 31.0 | 31.9 | 35.3 | 16.... | 30.77 | 31.63 | 32.03 | 35.30 | 41 | 24 | 32 |
| 18 Max | 30.3 | 31.3 | 31.8 | 35.0 | | | | | | | | |
| 18 Min | 29.4 | 30.9 | 31.5 | 34.9 | 18.... | 29.90 | 31.13 | 31.60 | 34.97 | 26 | 24 | 25 |
| 19 Max | 31.0 | 31.4 | 32 0 | 35.1 | | | | | | | | |
| 19 Min | 29.8 | 30.8 | 31.6 | 34.9 | 19.... | 30.27 | 31.10 | 31.77 | 35.00 | 27 | 18 | 22 |
| 20 Max | 30.3 | 30.9 | 32.0 | 35.2 | | | | | | | | |
| 20 Min | 26.7 | 29.9 | 31.5 | 35.0 | 20.... | 28.50 | 30.40 | 31.75 | 35.10 | 29 | 8 | 18 |
| 21 Max | 29.0 | 30.2 | 31.7 | 35.0 | | | | | | | | |
| 21 Min | 25.2 | 29.4 | 31.0 | 34.7 | 21.... | 26.73 | 29.67 | 31.37 | 34.87 | 21 | 9 | 15 |
| 22 Max | 24.7 | 28.8 | 31.2 | 34.7 | | | | | | | | |
| 22 Min | 20.0 | 28.3 | 31.1 | 34.4 | 22.... | 22.20 | 28.60 | 31.10 | 34.57 | 14 | 8 | 11 |
| 23 Max | 27.40 | 29.4 | 31.4 | 34.3 | | | | | | | | |
| 23 Min | 22.9 | 28.4 | 31.0 | 34.0 | 23.... | 25.63 | 28.83 | 31.13 | 34.17 | 30 | —3 | 8 |
| 25 Max | 27.2 | 28.2 | 31.2 | 33.7 | | | | | | | | |
| 25 Min | 20.2 | 26.6 | 30.6 | 33.4 | 25.... | 24.50 | 27.57 | 30.93 | 33.53 | 27 | 13 | 20 |
| 26 Max | 26.5 | 26.9 | 31.0 | 33.8 | | | | | | | | |
| 26 Min | 18.0 | 25.7 | 30.2 | 33.3 | 26.... | 22.93 | 26.30 | 30.53 | 33.47 | 23 | 5 | 14 |
| 27 Max | 25.1 | 25.8 | 30.6 | 33.5 | | | | | | | | |
| 27 Min | 17.8 | 23.0 | 29.9 | 33.0 | 27.... | 22.03 | 24.77 | 30.33 | 33.23 | 25 | 7 | 16 |
| 28 Max | 23.7 | 23.0 | 29.9 | 33.3 | | | | | | | | |
| 28 Min | 18.8 | 22.0 | 29.4 | 32.8 | 28.... | 20.83 | 22.67 | 29.57 | 33.00 | 10 | —6 | 2 |
| 29 Max | 20.0 | 22.3 | 29.6 | 33.0 | | | | | | | | |
| 29 Min | 14.5 | 20.8 | 29.0 | 32.5 | 29.... | 17.10 | 21.37 | 29.20 | 32.73 | 13 | —13 | 0 |
| 30 Max | 21.2 | 21.1 | 28.8 | 32.8 | | | | | | | | |
| 30 Min | 7.5 | 15.6 | 27.0 | 32.3 | 30.... | 16.27 | 18.37 | 27.90 | 32.60 | 18 | —13 | 2 |
| Ave. Max | 28.79 | 29.65 | 31.51 | 34.82 | | | | | | | | |
| Ave. Min | 24.95 | 28.66 | 31.11 | 34.55 | Ave... | 27.13 | 29.20 | 31.30 | 34.70 | 27.96 | 13.80 | 20.64 |
| Ave. Range | 3.84 | 0.99 | 0.40 | 0.27 | | | | | | | | |

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From an examination of the above table it will be seen that as a monthly average the soils covered with snow had a higher temperature than the bare. Indeed, the soil covered with the uncompacted snow and layer of vegetation did not freeze and its temperature was about 7°F higher than that of the bare, while the plots with the compacted and uncompacted snow were about 2 and 4°F warmer, respectively.

The daily records show that whenever the air temperature fell very low that of the bare soil also would go down many degrees lower than that of the other soils. Thus, for instance, on January 30, which was a cold day the average temperature ranged as follows in the various plots: bare 16.27°, compacted 18.37°, uncompacted 27.90°, and uncompacted with vegetation 32.60°F. While the minimum temperature for the same day ran as follows: bare 7.5°, compacted 15.60°, uncompacted 27.0°, and uncompacted with vegetation 32.2°F. The influence, therefeore, of snow upon soil temperature in the winter is very great.

## EFFECT OF TOPOGRAPHIC POSITION ON SOIL TEMPERATURE.

Considerable is already known concerning the effect of topographic position on soil temperature. Since, however, it was resolved to investigate the general subject of soil temperature as systematically and thoroughly as possible in order to arrive at definite and safe conclusions, a study of this phase was also conducted. This part of the investigation consisted in making observations on soil temperature at various topographic positions, namely, at a south slope, north slope, top of a hill, at a river bank, and at a low land. All these points were located within a small area. The river was situated between the north and south slope. The altitude and angle of these slopes were of medium magnitude. The altitude of the hill, which was the top of the north slope was also comparatively small. The soil of the low land was muck, that of the other locations was a sandy loam. The temperature was recorded three times a day, daily except Sunday, at 3 inches depth, by means of soil mercury thermometers. The surface of all these soils was kept free from vegetation. The data obtained from this series of observations are presented in Table 89. On account of limited space only the monthly maximum, minimum, amplitude and average temperature are given.

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TABLE 89.—MONTHLY, MAXIMUM, MINIMUM, AMPLITUDE AND AVERAGE TEMPERATURE OF SOIL AT VARIOUS TOPOGRAPHIC POSITIONS.

| 1915. | March. | | | | April. | | | | May. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| South Slope | 40.15 | 34.84 | 5.31 | 37.24 | 56.89 | 47.29 | 9.60 | 52.32 | 61.28 | 52.78 | 8.50 | 57.42 |
| River Bank | 34.02 | 33.02 | 1.00 | 33.44 | 49.99 | 45.27 | 4.72 | 47.33 | 54.75 | 49.82 | 4.93 | 52.42 |
| North Slope | 37.28 | 33.88 | 3.40 | 35.39 | 55.00 | 46.64 | 8.36 | 50.93 | 58.44 | 51.44 | 7.00 | 55.11 |
| High Point | 36.89 | 33.81 | 3.08 | 35.29 | 53.71 | 45.36 | 8.35 | 50.14 | 58.77 | 50.80 | 7.97 | 55.10 |
| Low land | 34.33 | 33.51 | 0.82 | 33.91 | 47.28 | 45.25 | 2.03 | 46.24 | 54.82 | 52.27 | 2.55 | 53.69 |

| 1915. | June. | | | | July. | | | | August. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| South Slope | 73.18 | 59.44 | 13.74 | 67.27 | 79.10 | 66.67 | 12.43 | 73.89 | 73.67 | 62.35 | 11.32 | 69.28 |
| River Bank | 62.82 | 56.18 | 6.64 | 59.92 | 69.06 | 63.77 | 5.29 | 66.84 | 65.30 | 60.62 | 4.68 | 63.36 |
| North Slope | 70.86 | 59.21 | 11.65 | 65.82 | 75.77 | 66.11 | 9.66 | 71.78 | 71.37 | 62.65 | 8.72 | 68.00 |
| High Point | 72.38 | 58.73 | 13.65 | 66.44 | 76.59 | 65.82 | 10.77 | 72.24 | 72.78 | 61.55 | 11.23 | 67.92 |
| Low land | 67.45 | 58.85 | 8.60 | 63.64 | 74.11 | 66.28 | 7.83 | 70.59 | 73.26 | 63.56 | 9.70 | 69.41 |

| 1915. | September. | | | | October. | | | | November. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| South Slope | 69.96 | 58.44 | 11.52 | 65.41 | 56.53 | 46.83 | 9.70 | 52.37 | 43.54 | 38.59 | 4.95 | 41.44 |
| River Bank | 63.10 | 59.90 | 3.20 | 60.58 | 54.85 | 47.35 | 7.50 | 51.82 | 43.56 | 38.99 | 4.57 | 41.26 |
| North Slope | 69.00 | 58.53 | 10.47 | 64.94 | 57.10 | 47.32 | 9.78 | 52.86 | 43.67 | 38.63 | 5.04 | 41.56 |
| High Point | 69.70 | 57.50 | 12.20 | 64.60 | 54.77 | 46.08 | 8.69 | 51.07 | 43.69 | 38.31 | 5.38 | 41.06 |
| Low land | 69.60 | 59.96 | 9.64 | 65.56 | 53.62 | 47.34 | 6.28 | 50.90 | 41.70 | 38.11 | 3.59 | 40.02 |

An inspection of the foregoing table shows that from March up to about September the average temperature of the south slope was about 2°F higher than that of the north and top hill, about 5 or 6°F than that of the river bank, and about 4 or 5°F than that of the muck up to June. From October on all the different locations had practically the same magnitude of temperature. As a rule, the greatest amplitude occurred in the south and north slope and high point, and the smallest in the river bank and low land or muck.

The daily records show that the temperature of the south slope would begin to rise earlier and faster in the morning during the spring months than that of the north. The reason for this is obvious.

The marked influence of the slant of the surface with respect to the position of the sun on the soil temperature is even manifested on a cultivated soil with a very rough and uneven surface. Observations made upon this point have yielded some exceedingly interesting and surprising results. Thus, for instance, it was found that that side of the lumps which faced the sun in the morning would possess as much as 5°F higher temperature than that side which was shaded. Even greater differences than these were obtained between the shaded and unshaded sides of a dead furrow. If the soil was sandy, the side facing the sun would thaw almost completely and its temperature would rise several degrees above the freezing point before the opposite side began to thaw.

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## EFFECT OF UNDERHEATING ON THE SOIL TEMPERATURE DURING THE WINTER.

It is a very general observation that the surface of a soil which is traversed underneath by a steam heat pipe is kept free from snow during the winter, and in the spring its vegetation commences to grow much earlier than that of the adjacent soil only a short distance away. The logical inference of these observations is that heat escapes from the steam heat pipe which keeps the surrounding soil warm.

In the winter of 1915 it was decided to undertake a series of observations to determine (1) to what extent the heat lost from a steam heat pipe, in the College Campus, keeps the soil immediately above warm, and (2) how far distant from the pipe the influence of the heat escaping will be felt. To obtain this information soil mercury thermometers were placed 3 inches deep, immediately over the pipe and at various distances apart, up to 10 feet, and temperature observations were made three tims a day throughout the winter. The pipe ran from one building into another and was very long, buried a little over a foot into the ground, and was very well insulated by asbestos, cement, etc. The data obtained from December up to and including April are presented in Table 90.

TABLE 90.—EFFECT OF UNDERHEATING ON SOIL TEMPERATURE IN THE WINTER.

| 1914-1915. | December. | | | | January. | | | | February. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| 0" | 52.70 | 51.51 | 1.19 | 52.15 | 60.35 | 57.46 | 2.89 | 58.82 | 68.04 | 63.68 | 4.36 | 65.88 |
| 2" | 45.06 | 43.63 | 1.43 | 44.35 | 47.51 | 45.60 | 1.91 | 46.69 | 50.62 | 47.57 | 3.05 | 49.20 |
| 4" | 38.01 | 36.90 | 1.11 | 37.41 | 38.17 | 37.05 | 1.12 | 37.68 | 40.05 | 37.88 | 2.17 | 39.04 |
| 5" | 35.60 | 34.79 | 0.81 | 35.13 | 35.64 | 34.75 | 0.89 | 35.20 | 36.78 | 35.35 | 1.43 | 36.04 |
| 6" | 34.08 | 33.22 | 0.86 | 33.62 | 33.54 | 32.86 | 0.68 | 33.20 | 34.83 | 33.67 | 1.16 | 34.23 |
| 7" | 33.43 | 32.63 | 0.80 | 33.03 | 32.61 | 32.04 | 0.57 | 32.36 | 33.90 | 32.86 | 1.04 | 33.38 |
| 8" | | | | | | | | | | | | |
| 9" | | | | | | | | | | | | |

| 1914-15. | March. | | | | April. | | | |
|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Diff. | Ave. | Max. | Min. | Diff. | Ave. |
| 0" | 99.02 | 91.90 | 7.12 | 96.02 | 83.87 | 72.96 | 10.91 | 79.65 |
| 2" | 71.23 | 65.48 | 5.75 | 68.79 | 75.87 | 66.70 | 9.17 | 72.40 |
| 4" | 52.72 | 46.47 | 6.25 | 50.09 | 67.43 | 59.02 | 8.41 | 64.30 |
| 5" | 42.94 | 38.21 | 4.73 | 40.67 | 61.77 | 53.33 | 8.44 | 58.39 |
| 6" | 42.83 | 37.62 | 5.21 | 40.55 | 59.24 | 50.68 | 9.56 | 55.59 |
| 7" | 40.74 | 35.95 | 4.79 | 38.52 | 56.24 | 46.60 | 9.64 | 52.28 |
| 8" | 39.38 | 35.24 | 4.14 | 37.20 | 55.95 | 45.90 | 10.05 | 51.93 |
| 9" | 38.15 | 34.17 | 3.98 | 36.14 | 55.45 | 45.33 | 10.12 | 51.39 |

The winter of 1915 was very cold, but in spite of that the heat escaped from the steam heat pipe kept the temperature of the soil immediately above very high, from 50 to 65°F, and even prevented the soil 7 feet away from freezing. Indeed, even at a distnce of 10 feet the soil tem-

perature was perceptibly influenced. Since the heat traveled in both opposite directions, then a lateral path of 20 feet was kept warm, but the degree of warmth, of course, decreased inversely with the distance.

As already stated, these temperature records were taken at 3-inch depth. At a lower depth, the magnitude of temperature would be greater at the respective distances.

It will be readily realized that the foregoing data are of considerable practical importance.

## CONCLUSIONS.

The soil temperature has been studied at this Station for four years. The results of the investigation for the first year have already been published in a previous report. In the present report there are presented the data obtained in the following three years and the general conclusion that might be deducted from the entire investigation.

The number of factors influencing the temperature of soil is very great. These factors may be divided into two main groups, (1) the intrinsic, and (2) the external. The intrinsic factors are those contained by the soil and include the specific heat, heat conductivity, radiation, water content, evaporation of water, concentration of soil solution, topographic position, condition of surface, etc. The external factors comprise the metereological elements and include the air temperature, sunshine, wind velocity, barometric pressure, rainfall, etc. The temperature of soil, therefore, is controlled by and is the resultant of these intrinsic and external factors. Part of these factors of both groups favor a high soil temperature and part a low, and whichever class predominates determines the degree of soil temperature at any time.

The intrinsic factors play a passive and the external an active role. In other words the intrinsic factors tend to remain passive but are acted upon by the external factors. Hence, the degree of soil temperature is almost wholly controlled by the external factors and especially the air temperature, but modified by the intrinsic factors. Inequality in temperature, therefore, in the different kinds of soil during the same day will depend upon the intrinsic factors but variation in temperature in any soil in succeeding days or seasons will depend upon the external factors.

All soils possess practically the same intrinsic factors but in different degree. Witness, for example, the great disproportionality between sand and peat. Indeed these soils possess most of the intrinsic factors in opposite degree. Thus for example, peat has black color, low heat conductivity, a high water-holding capacity, etc. These same properties exist in sand in almost exactly the opposite degree. Hence a law of compensation intervenes.

This unparallelism of the various intrinsic factors in the different kinds of soil tends to give the latter an equal degree of average temperature. In other words each type of soil possesses the various intrinsic factors in a compensating or neutralizing degree and consequently

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they all tend to have the same average temperature under the same meteorological elements.

In excessive degree, however, certain of the intrinsic factors predominate and cause a variation in the temperature of the diverse classes of soil. The factors which are almost always responsible for differences in temperature that may exist in the different kinds of soil are the following: (1) latent heat of fusion of ice, (2) latent heat of evaporation of water, (3) a covering of the surface soil, (4) color, and (5) topographic position. All these factors are able to exert either an ephemeral or lasting predominant effect upon the temperature of the soil which possesses them.

The line of thought thus far developed is supported by the results obtained from the various experiments conducted under natural conditions.

The field studies on the temperature of different types of soil, namely, gravel, sand, humus loam, clay, and peat at 6, 12 and 18-inch depths, showed that when the surface of all these soils was covered with a thin layer of sand they had almost exactly the same average temperature throughout the year except during a short period in the spring when thawing was taking place.

Thawing would usually commence about the end of March or beginning of April. The sand and gravel would thaw completely first, followed by clay and loam, one or two days later, and peat ten or fifteen days later. Immediately upon complete thawing the average temperature of the mineral soils would rise rapidly and approach the same magnitude in about three or four days. Meantime the average temperature of the peat would be far below, on account of the slow rate of thawing. As soon, however, as it was also completely thawed its temperature would rise very rapidly and would approach, in a few days, that of the mineral soils. The average temperature then of all the soils would be remarkably the same from this period on throughout the summer, fall and winter months until the next thawing period.

During the summer months the peat would have a monthly average temperature of a few tenths of a degree higher than the mineral soils. In the fall, however, the sand and gravel would possess a slightly higher monthly average temperature than the peat.

Whenever rapid and sudden changes of air temperature occurred the sand and gravel would warm and cool the fastest, followed by clay, loam and peat, respectively. The equilibrium or equality, however, would quickly be reestablished.

The degree of amplitude was greatest in sand and gravel, somewhat smaller in loam and clay, and least in peat. The highest fluctuation occurred in summer and the lowest in winter.

The maximum temperature was approximately the same for all types of soil, after complete thawing had taken place, but the minimum varied somewhat; it was lowest in sand and gravel, slightly higher in clay and loam, and highest in peat. Even during the winter, the minimum varied only slightly in the different soils. During a sudden severe cold weather, however, the minimum of the sand and gravel would fall appreciably lower than that of the peat, but the differences would not be very great.

The equality of average temperature in the diverse classes of soil, therefore, was not made up of extreme variation in the maximum and minimum temperature between them, i. e., a very high maximum and

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low minimum in one soil and a low maximum and high minimum in another.

The uniformity of average temperature throughout the year except during the short period in the spring when thawing was taking place, of the different types of soil when their surface was covered with a thin layer of sand, is really remarkable. It shows that there was only one intrinsic factor, the heat of fusion of ice, which predominated and caused a variation in their average temperature and especially between sand or gravel and peat. All the other intrinsic factors existed in such a compensating degree and order in these different kinds of soil that they caused and maintained in them an equal magnitude of temperature, after complete thawing took place.

When these same types of soil, however, were not covered with a thin layer of sand but their natural surface was allowed to be exposed to the atmosphere somewhat different results were obtained. Their average temperature, instead of being equal throughout the year except during the process of thawing, was about the same only during the fall and winter months, but varied somewhat during the spring and summer months. During the latter seasons the sand and gravel would have the highest average temperature, the clay and loam slightly lower, and peat the lowest. The difference, however, between the mineral soils was comparativly small, but the variation between the sand or gravel and peat was quite appreciable, especially in the early spring when thawing was taking place. By the commencement of fall, however, these differences would disappear and all the soils then would have the same magnitude of average temperature, and would continue to be equally warm until the next thawing period, in almost exactly the same way as when they were covered with the thin layer of sand. In the spring the peat would not thaw and its temperature would not approach that of the mineral soils after complete thawing, as rapidly as when its surface was covered with the thin layer of sand.

Besides the average temperature the order of the maximum and minimum temperature also differed in the various types of soil under the two surface conditions. As previously stated when the surface of these soils was covered with a thin layer of sand their maximum temperature was approximately the same in all of them, but the minimum varied somewhat; the sand and gravel would usually be the coldest in the morning followed by clay, loam and peat, respectively. But when their surfect was not covered, this order of the maximum and minimum temperature was just reversed.

The inequality in average temperature during the spring months, after complete thawing had taken place, and also during the summer months, of the different types of soil when their natural surface was allowed to be exposed to the atmosphere, indicates that there was one intrinsic factor, the heat of evaporation of water, which predominated and caused the variation. The clay and loam, and especially the peat having a greater percentage of water than the sand and gravel, lost more water by evaporation than the latter and consequently their average temperature was kept correspondingly lower. When the surface of all the soils, however, was covered with the thin layer of sand, the excessive evaporation of the clay, loam and peat was reduced and consequently their



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average temperature was raised to the same magnitude as that of the sand and gravel.

There are good reasons to believe, that a cover of growing vegetation would cause identical equality of average temperature in the diverse types of soil as the cover of sand. Hence, variations in temperature that are observed in these soils in bare condition, may not exist when they are under crops, i. e., after complete thawing has taken place.

The remarkably even magnitude of average temperature of the different types of soil, both when their surface was covered and uncovered, in the fall and winter months, is of the greatest interest. It shows that there was no one single factor during these seasons, not even the specific heat of water, which had a predominant and controlling influence in causing these various soils to cool differently and be unequally warm.

The rapidity with which the clay and loam thawed and the rise of their temperature to the same degree as that of sand and gravel in such a short time, both when their surface was covered and not covered with sand, contradicts the exaggerated general belief that these soils possess a greatly lower temperature during the spring and therefore should be classed as cold soils. This last term, however, may be justly applied to peat, especially when it is not covered with sand.

There was some heat coming to the surface during the winter from the lower and warmer depths which tended to keep the temperature of the upper depths higher, and aided in the thawing and raising the temperature in the spring. The average air temperature was lower than that of any soil at the 2, 4, 6, 12 and 18-inch depths, throughout the year. The amplitude of the air temperature, however, was far greater than that of all the soils at any of the above depths, also throughout the year.

The maximum temperature of all the soils at one quarter of an inch depth was about 30°F higher during hot and clear days than that of the air at an elevation of four feet.

The minimum temperature of all the soils except peat, however, immediately at the surface was only about 1 or 2°F higher, as a monthly average, than that of the air at a height of four feet. That of the peat was slightly lower than that of the air.

Unless the various soils were frozen they always had a gradient of temperature at their adjacent depths. This gradient of temperature, however, reversed itself between day and night during the warm part of the year to the depth that the diurnal-nocturnal amplitude of oscillation of temperature extended. During the day it decreased from the surface downward and during the night the reverse was true. There were two periods, one in the morning and one in the evening, when the reversion took place, that this gradient was not regular. During the day, at the time that the maximum temperature was attained at the surface, this gradient was very large at the adjacent dephts, the difference between the surface and the 6-in. depth being sometimes as high as 30° F, but during the night at the time when the minimum was reached at the surface, it was comparatively small, the greatest differences between the same depths being only about 10°F.

The soils, down to the depth that the diurnal-nocturnal amplitude of oscillation of temperature extended, received their temperature in the form of waves. There were, of course, two types of waves, a warm and a

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cold. Both of these classes of waves penetrated the soils in gradual increase of intensities of temperature.

The rate at which the maximum and minimum temperature waves traveled through any particular soil tended to follow approximately a mathematical law. This law may be stated thus: The lag of the maximum and minimum epochs tended to be approximately proportional to the depth, in all the different types of soil.

The decrease of the diurnal-nocturnal amplitude of temperature with the increase in depth also followed a mathematical law in all the diverse types of soil and indeed the geometric progression law. This law may be stated as follows: The diurnal-nocturnal amplitude of oscillation of temperature decreased in geometric progression as the depth increased in arithmetric progression, in all the different types of soil.

The four years' data obtained on the temperature of sand to which was added different percentages of organic matter (peat) showed that during the fall and winter months all these soils had approximately the same degree of average temperature but in the spring and summer months it varied somewhat. During the latter months the sand which received no organic matter and had a white-colored surface and the peat had about the same and lower average temperature than the other soils which were treated with various percentages of peat.

In the spring all the treated and untreated mineral soils would thaw first and approximately at the same time, the peat, however, would thaw last and several days later.

The amplitude of temperature at the 3 and 5-inch depths was high but approximately of equal degree in all the treated and untreated soils, but comparatively low in the peat.

The higher average temperature of the sand to which was added various quantities of peat during the spring months after thawing, and in the summer months, over the sand which received no peat and had white-colored surface, and the peat, goes to prove that the white color reflected so much of the solar energy that it kept the temperature of white sand low in spite of the many other intrinsic factors which are favorable for a high temperature. On the other hand a large amount of evaporation of water predominated over the high heat absorptive power of the black color and consequently kept the temperature of the peat also low. Soils, however, possessing these properties in medium degree maintained a higher average temperature during the same periods.

The general belief that there exists a large difference in temperature between a cultivated and uncultivated soil is much exaggerated. The observations conducted for four years show that the uncultivated soil had practically the same or only a few tenths of a degree higher temperature during the spring months than the cultivated, and only about 1°F higher during the summer months. During the fall and winter months there was hardly any difference.

There did exist, however, a very marked difference in average temperature between thse two bare soils and one covered with growing vegetation. The data show that immediately upon the commencement of growth of the vegetation the temperature of the sod or grass land would become decidedly lower than that of the cultivated and uncultivated soil. The maximum difference would be reached in June and July when the sod soil at the 7-inch depth for instance would be about 6°F

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colder than the bare soils. This difference, however, would become smaller and smaller so that by September it would entirely disappear and by October the order would be reversed; the bare plots would become colder and the sod warmer. The latter would continue to have a higher temperature throughout the fall and winter months.

A cover of vegetation, therefore, had a very large controlling influence upon the soil temperature; during the warmest part of the year it kept the soil cold and during the coldest part, warm. Indeed, a cover of vegetation is one of the most efficient and expedient means of protecting the soil against extreme low temperature during the winter.

Like the vegetation cover, a thick layer of snow is also a most efficient agent for keeping the soil warm in the winter and preventing it from attaining extreme low temperature during severe cold weather. Observations made for four years upon this subject showed that in exceptional cold weather the soil covered with a vegetation cover and a layer of snow would have 25°F higher temperature than a bare soil at 3-inch depth.

Certain topographic positions have a marked controlling influence upon the soil temperature. A southern exposure had about 2°F higher average temperature than a northern during the spring and summer months, but during the fall and winter months both locations would be equally warm. The soil temperature at a river bank was far below that of the south and north slope during the spring and summer months but slightly higher during the fall and winter months.

The marked influence of the slant of the surface with respect to the position of the sun on the soil temperature is even manifested on a cultivated soil with very lumpy and uneven surface. The sides of the lumps or dead furrows facing the sun in the morning had a higher temperature than those shaded.

The heat escaping from a well-insulated steam pipe buried about a foot into the ground influenced the temperature of the surrounding soil to a considerable extent. The temperature of the soil was highest immediately above the pipe and diminished with increase in distance. The influence was felt and the soil was prevented from freezing to a distance of about 10 feet on each side, making a total lateral distance of about 20 feet.

Speaking broadly, the ability of man to control or influence the soil temperature under field conditions, one way or the other, is greatly limited. Since the temperature of the soil is finally dependent upon the meteorological elements and especially upon the air temperature, which are beyond his control, all he can do is to vary some of the intrinsic factors and thereby modify somewhat the degree of soil temperature, either temporarily or permanently. The factors which are in his power to modify in order to hasten the rise of temperature in the spring, which is the most important time, are: (1) draining the soil from an excess of water, (2) creating a dark color at the surface, (3) covering the surface of these soils prone to low temperature with a thin layer of sand, and (4) compacting the surface of the cultivated soil.

A fulfillment of the above factors except (1) would probably be of some benefit only if the planting is to be done in the spring. If it is already accomplished in the fall so that the plants have already begun

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to shade the ground then the creation of conditions (2), (3), and (4) would be of practically no important benefit.

Furthermore, by creating conditions (2), (3), and (4) the temperature of the heavy types of the mineral soils could hardly be increased more than 2°F; that of the peat, however, could be raised almost twice this amount. The practical importance of this comparatively small increase in average temperature, therefore, would depend upon the sensitiveness of the germinating seed and growing plant upon the temperature and upon the time of the growing season.

Again, it must be remembered, that it is not only the soil temperature that influences the growth of plants, but the air temperature as well. Hence, if the air temperature is the same over a certain area then the influence of small variation of temperature that may exist in adjacent different types of soil would be of lesser significance.

Some of the intrinsic factors which man can modify to keep the soil warm or protect it from extreme low temperature in the winter are: (1) covering the soil with straw or any other material, and (2) heating the soil.

Man can regulate the soil temperature far easier, more successfully and probably with far greater practical results during the cold part of the year than at any other other time.

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MICHIGAN AGRICULTURAL COLLEGE.

EXPERIMENT STATION.

DIVISION OF SOILS

# The Freezing Point Method as a New Means of Determining the Nature of Acidity and Lime Requirement of Soils.

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EAST LANSING, MICHIGAN
1916.

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## INTRODUCTION.

Perhaps no other single subject in soils is receiving at present more attention and investigation than that of soil acidity. Again, probably no other soil problem is so rich in laboratory methods[1] as the acidity of soils. Both of these facts unmistakably go to indicate that the subject *per se* is of urgent importance and that probably none of the present methods is proving entirely satisfactory for its solution.

That the subjct is of great and urgent practical importance can scarcely be questioned. It appears now to be an established fact that the so-called acidity of soils is proving to be a limiting factor in crop growth, at least for many agricultural plants, and that the infertility of many soils, in part or in whole, may be safely attributed directly or indirectly, to this factor. The necessity, therefore, of correcting this acid condition of soils and thereby rendering them more efficient and productive, is of paramount importance.

Experience has shown that when the acid soils are treated with lime in its various forms the growth of some crops is greatly increased, while that of others, very little if any. This has led to the logical conclusion that the acid condition of soils affects the various plants differently.

Since this is true, then it would appear that probably no soil acidity laboratory method could ever be expected to tell exactly to what extent the soil acidity should be corrected by the application of lime. This point would have to be settled by field experiments.

Most that a soil acidity laboratory method might ever be expected to do from the practical standpoint, is to show the maximum lime requirement of soils and then apply the lime according to the crops planted. Any soil acidity laboratory method, therefore, that would be able to indicate definitely and correctly the maximum lime requirement of soils, would be of the greatest value.

It appears very doubtful if any of the present soil acidity methods gives the true lime requirement of soils. Thus, take the Veitch method which is quite generally considered to be probably the most satisfactory from the practical standpoint, i. e., it comes closer in indicating the true lime requirement of soils than any other method, although many of the other methods show almost identical results. A critical consideration of the nature of the soil mass and the kind of indicator employed seems to point very strongly to the fact that this method probably does not indicate the total maximum lime requirement of soils. A consideration of the soil mass shows that it is composed mainly of silicates of the metals aluminum, iron, calcium, potassium, sodium, and magnesium.

(1) It is not deemed necessary to review the numerous soil acidity methods that have been proposed, since several of the recent articles on soil acidity contain quite complete reviews of these different methods. Perhaps the most complete resume of all the various soil acidity methods is contained in a recent bulletin written by Dr. W. Frear entitled: Sour soils and Liming. Bulletin 261, Dept. of Agr., Commonwealth of Pennsylvania.



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These silicates are salts of strong bases with weak acids, and being somewhat soluble in water are greatly hydrolyzed. Upon hydrolysis the acid remains more or less in an insoluble form while the bases go readily into solution. Now it is a well known fact that the strength of the bases and acids has a very marked effect upon the indicators commonly employed for determining the end point of neutralization. Thus, for example, phenolphthalein cannot be used with weak acids or weak bases. If the acid is so weak that its salts, even with strong bases, are hydrolyzed, the free base begins to react with phenolphthalein long before enough base has been added to completely neutralize the acid. The result is the appearance of a faint color on the addition of a little alkali. In the Veitch method phenolphthalein is employed as the indicator. Now it is readily evident that if the soil contains soluble weak acids consisting of silicic and organic acids, the alkali color begins to manifest itself long before enough of the base is added to completely neutralize all the soluble weak acids present. The result is that the soil shows a low lime requirement and consequently its true maximum lime requirement will not be known.

As it will be subsequently shown, however, *the acidity of the mineral soils appears to be due almost entirely to the acid alumino-silicates, silicic acid, and silica, and that the mineral soils rarely if ever contain permanently free soluble acids.* Consequently the above objection to using phenolphthalein in the Veitch method is neither absolutely valid nor so serious. The aforesaid objection, however, would hold true in the hydrolysis of the minerals. As already stated these silicates or silico-minerals upon hydrolysis yield soluble bases and more or less insoluble acid. If the bases are present even in small quantities they will give a neutral or alkaline reaction both to the phenolphthalein and litmus paper, even if the silicates are far from being completely neutralized, or satisfied with a base. This is due of course to the high ionization of the bases and consequently to their strong reaction upon the indicator as compared with the almost negligible ionization of the acid and therefore its extremely weak reaction upon the same indicators. It is very possible to have a soil which would be neutral according to the Veitch method and litmus paper test and yet this soil may possess a large amount of negative or inactive acidity, as it is generally termed, i. e., the acid radical of the soil, which is composed almost entirely of alumino-silicate, silica and silicic acid, is far from being entirely satisfied with bases.

A simple experiment, which apparently would seem to demonstrate the validity of the above statements and at the same time help to make the point in question more clear, may be cited as follows: If to 1 gram of pure silicic acid is added 10 c. c. of distilled water and the mixture stirred and a blue litmus paper is placed into it, the color of the litmus paper will shortly turn decidedly red. If now to this mixture is added a few drops of N/25 $Ca(OH)_2$ the red will shortly turn faint blue or neutral and continue to remain faint blue or neutral. Yet this one gram of silicic acid requires nearly 80 c. c. N/25 $Ca(OH)_2$ to be fully satisfied before the $Ca(OH)_2$ can remain in solution to affect the concentration of the liquid phase, and therefore, also the freezing point depression. In other words, the $Ca(OH)_2$ added to the silicic acid immediately combines with it to form calcium silicate and

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thereby is removed from the liquid phase. The $Ca(OH)_2$ which is in solution is that only which is due to hydrolysis of the calcium silicate compound. When the silicic acid, however, is fully saturated or satisfied with the $Ca(OH)_2$ then the hydrate will remain in the solution and affect the freezing point depression. In spite of this tremendous amount of lime absorption or requirement by the silicic acid, a neutral reaction is attained, according to the phenolphthalein and litmus paper indicators, when only about one-hundredth of the amount required is added.

That the hydrolisis of the soil minerals and the effect of the resulting products upon the phenolphthalein indicator play a large role in the estimation of the lime requirement of soils by the Veitch method seems to have been recognized by Veitch himself, although he does not appear to have attached any serious consequences to the matter. Veitch found that the length of time the treated soil was allowed to stand had considerable effect upon the lime requirements.[2] When the solution was allowed to go on from 48 to 72 hours the pink color with phenolphthalein was developed with less added lime water than when the solution was allowed to stand 16 hours or less. Furtheromer, Veitch found that some soils which were acid when allowed to stand 16 hours gave an alkaline filtrate when permitted to stand 24 to 48 hours longer.

Any one who has tried to test soil acidity with the litmus paper test will doubtless have noticed that many soils, even those which show lime requirement by the Veitch method, will turn the red litmus pink or neutral on long standing, especially when the soil is treated with an excess of water. This phenomenon can safely be attributed to hydrolysis.

Veitch's method calls for treating the soil with water and $Ca(OH)_2$ and then drying down at once on a steam bath. Now it is a well known fact that hydrolysis is appreciably increased by a rise in temperature.

Even practical experience seems to indicate that the Veitch method may not be showing the true maximum lime requirement of soils, and consequently the proper amount of lime may not be applied to the soils for the successful growth of crops. Thus, for instance, in a recent paper by Ames and Schollenberger of the Ohio Experiment Station[3], it is shown that the soil of some of the experimental plots, which was limed a long time ago, is now almost neutral or alkaline according to the Veitch method, yet the growth of clover will be materially benefited by an application of lime. In speaking of the possible usefulness of the various methods for comparative purposes when different soil treatments have been made, Ames and Schollenger make the following statement: "If either the Hopkins or the Veitch test were used to obtain a figure for the limed soil's requirement, the results would lead to erroneous conclusions, because the Veitch method indicates that the limed halves of all the plots are alkaline...." Yet an application of lime to these plots will materially benefit the growth of clover.

The behavior of the Veitch method towards this soil which was limed a long time ago but with amounts which were evidently too small, since the growth of clover will be enhanced with further applications, is in perfect agreement with the theory of hydrolysis and the reactivity of the hydrolyzed products upon the phenolphthalein indicator, as already set forth.

Thus far an attempt has been made to show that probably none of the

(2) Jour. Am. Chem. Soc. 24 (1904), 637.
(3) Jour. Ind. Eng. Chem. 8 (1916), 243.

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methods now in vogue are capable of indicating the total maximum lime requirement of soils. The Veitch method has been mainly taken into the discussion because it is generally considered to be the standard method. The other methods are based upon different principles and although the individual criticisms would accordingly vary, yet the main and important criticism, namely that they may not indicate the total maximum lime requirement of the soils, is the same. It will have been noticed that nothing has been said concerning the empirical nature of these methods, the comparatively slight variations in methods of procedure affect the result obtained markedly. The errors arising from this source, however, serious as they may be, are insignificant in comparison with the above main objection.

It is hoped that the foregoing critique will not be considered as a condemnation of any of the soil acidity methods, and especially of the Veitch method! Indeed that is far from being the intention and desire of the writer. He fully realizes and acknowledges their usefulness. In offering these criticisms it is done with the firm belief that they are based upon fundamental principles and experimental data; and incidentally to emphasize the need of some new method which will indicate definitely and accurately the true lime requirement of soils.

In employing the freezing point method to measure the concentration of the soil solution directly in the soil; the effect of the application of fertilizers upon the concentration of the soil solution[4]; the concentration of the cell sap directly in the plant tissue[5]; and the effects of biological activities directly in the soil[6], the idea occurred that the freezing point method might also be employed to determine or study both the nature of soil acidity and the lime requirement of soils. It was reasoned that if the soil contains a free soluble acid, this acid would possess a definite freezing point depression at a certain concentration. Upon titrating this acid with a base, such as $Ca(OH)_2$, a salt would be formed. This salt would probably possess a different freezing point depression from that of either of the reacting agents. The depression then should vary as more and more of the lime is added to the soil until the neutralization point is reached where the formation of the salt is completed and then the direction of the depression should change. If on the other hand, the soil does not contain a free soluble acid but possesses an absorptive power for lime, due to its unsaturated or unsatisfied silicate compounds and organic matter, then the depression of the freezing point of the soil should remain the same as more and more lime is added until these silicate compounds and organic matter are satisfied with the base, and then it should increase with further addition of $Ca(OH)_2$. Finally, if the soil is alkaline or already saturated with bases, then the depression should begin to rise immediately upon adding a small amount of $Ca(OH)_2$ to the soil.

Happily all these *a priori* predictions were actually and experimentally realized in soils exactly as they are described above.

The freezing point method then promises of being capable to perform three functions simultaneously: (1) to indicate whether or not a soil needs lime, (2) the quantity it requires, and (3) the nature of its acidity.

(4) Tech. Bul. 24, 1915, Mich. Expt. Sta.
(5) J. Am. Soc. Agr. 8, 1916.
(6) Science, 44, 65, 1916.

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Using the Veitch method as a standard for comparison, the freezing point method shows that the soils and especially the loams, clays and mucks or peats, require far greater amounts of lime to satisfy completely their unsaturated compounds than the former method does. It appears that this maximum requirement as obtained by the freezing point method represents the true lime requirement of soils. *By true lime requirement is meant the total maximum amount of lime required by the soils to neutralize any of their soluble acid or acid salts, and to satisfy their absorption-adsorption phenomena for* $Ca(OH)_2$.

While the freezing point method probably indicates the true lime requirement of soils, no claim is made that it is necessary to add all that amount of lime to the soils; this point will ultimately have to be decided in the field, using the plant as the indicator. As previously intimated, probably no laboratory method, including the freezing point method, could ever be expected to designate definitely how much lime should be added to the soil. This is clearly obvious from the fact that the plant is used as an indicator to determine the effects of acidity and basicity upon its growth, and since it is found that different plants are affected differently by these qualities. All that a laboratory method might ever be expected to do, at least from the practical standpoint, is to show the maximum lime requirement of the soils and then apply the lime to these soils according to the requirement of the crops planted. This certainly appears to be the most rational and intelligent procedure. However, the experience of various observers goes to indicate very strongly that heavy applications of lime increase the growth of most crops very markedly, and these quantities are in accordance with those indicated by the freezing point method.

In the present bulletin, therefore, there is presented the freezing point method as a new method for determining the lime requirement of soils and possibly the nature of their acidity; also the principles and description of the method; and some of the experimental data obtained.

## PRINCIPLE OF THE METHOD.

As already stated the principle of the freezing point method for determining the nature of soil acidity and lime requirement is based upon the following facts: (1) That if a soil contains a soluble acid or acid salt its freezing point depression decreases more or less regularly and gradually with the increase in the amount of $Ca(OH)_2$ added until the points of neutralization and saturation are reached and then it begins to increase. (2) If on the other hand a soil contains neither a soluble acid nor an acid salt but possesses an absorptive power for lime, due probably to the unsatisfied silicate compounds and organic matter, the freezing point depression remains constant as more and more of $Ca(OH)_2$ is added to the soil, until the absorptive power is satisfied and then the freezing point depression commences to rise. (3) Finally, if the soil contains neither a free soluble acid or acid salt, nor an absorptive power

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for lime, i. e., it is already alkaline and satisfied, then the freezing point depression starts to ascend almost immediately upon the addition of a small amount of $Ca(OH)_2$. These principles are clearly illustrated by the following examples.

The first principle, that the freezing point depression of a soil containing a soluble acid or acid salt decreases with increased amount of $Ca(OH)_2$ added until the point of neutralization is reached and then begins to increase, was established (1) by pure acids and acid salts, and (2) with soils to which were added acids and acid salts. In Table 1 there are shown the freezing point depressions of HCl, $H_2SO_4$, $H_2C_2O_4$ and $Al_2(NO_3)_6$ in pure solutions titrated with $Ca(OH)_2$. These results are graphically represented in figures 1a, 1b, 1c and 1d. In order to avoid the factor of dilution of the reagents, the acids and acid salts were sufficiently diluted to make their freezing point depression much smaller than that of the $Ca(OH)_2$ whose depression was .105° C. It should be stated that the results below are presented solely to illustrate the principle and not necessarily the exact neutralization point.

TABLE 1. THE FREEZING POINT DEPRESSION OF HCl, $H_2SO_4$, $H_2C_2O_4$ AND $Al_2(NO_3)_6$ TO WHICH WERE ADDED DIFFERENT AMOUNTS OF $Ca(OH)_2$.

| Reagents. | Depression. |
|---|---|
| HCl | .055°C |
| plus 2 c. c. $Ca(OH)_2$ | .045 |
| plus 1 c. c. $Ca(OH)_2$ | .040 |
| plus 1 c. c. $Ca(OH)_2$ | .039 |
| plus 1 c. c. $Ca(OH)_2$ | .041 |
| plus 1 c. c. $Ca(OH)_2$ | .045 |
| $H_2C_2O_4$ | .040°C |
| plus 3 c. c. $Ca(OH)_2$ | .021 |
| plus 2 c. c. $Ca(OH)_2$ | .010 |
| plus 2 c. c. $Ca(OH)_2$ | .000 |
| plus 1 c. c. $Ca(OH)_2$ | .002 |
| plus 5 c. c. $Ca(OH)_2$ | .025 |
| $H_2SO_4$ | .048°C |
| plus 3 c. c. $Ca(OH)_2$ | .030 |
| plus 1 c. c. $Ca(OH)_2$ | .029 |
| plus 1 c. c. $Ca(OH)_2$ | .031 |
| plus 4 c. c. $Ca(OH)_2$ | .046 |
| $Al_2(NO_3)_6$ | .060°C |
| plus 2 c. c. $Ca(OH)_2$ | .057 |
| plus 4 c. c. $Ca(OH)_2$ | .050 |
| plus 2 c. c. $Ca(OH)_2$ | .051 |
| plus 5 c. c. $Ca(OH)_2$ | .061 |

An inspection of the foregoing results bears out perfectly what has already been said, namely, the freezing point depression of the acids and acid salts decreases as more and more Ca $(OH)_2$ is added to them until a certain point, the neutralization point, is reached and then it commences to increase with further addition of the hydrate.

Now it will be of interest to know whether the same general results are obtained when these acids and acid salts are added to the soil and the titration is done in the soil. Table 2 contains the results of a few typical experiments bearing upon this point. These results are graphically represented in figures 2a, and 2b. The experiments consisted of adding 10 c. c. of the acids or acid salts to 2 grams of soil and then following the same procedure as in the case of the pure solution.

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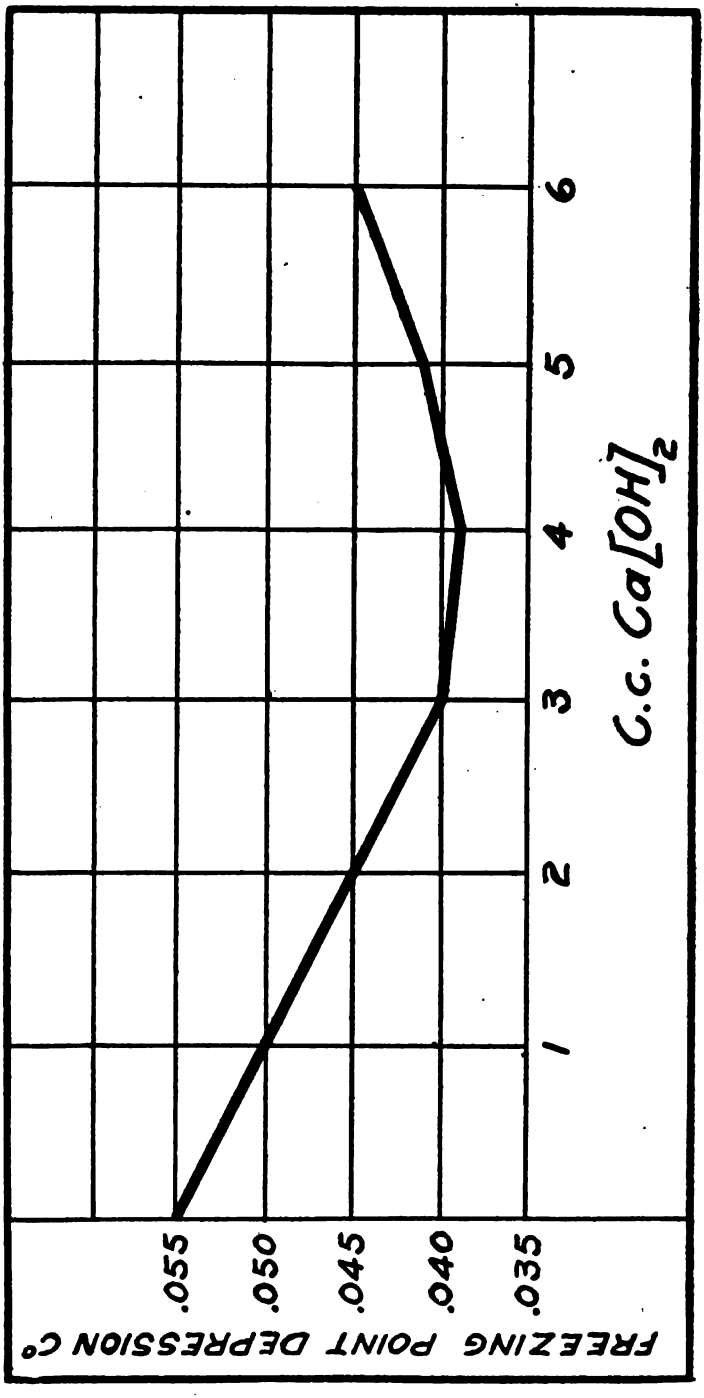


FIGURE 1a. Curve showing the decrease in the depression of HCl by the addition of $Ca(OH)_2$ down to a certain point and then the increase with further addition of $Ca(OH)_2$.

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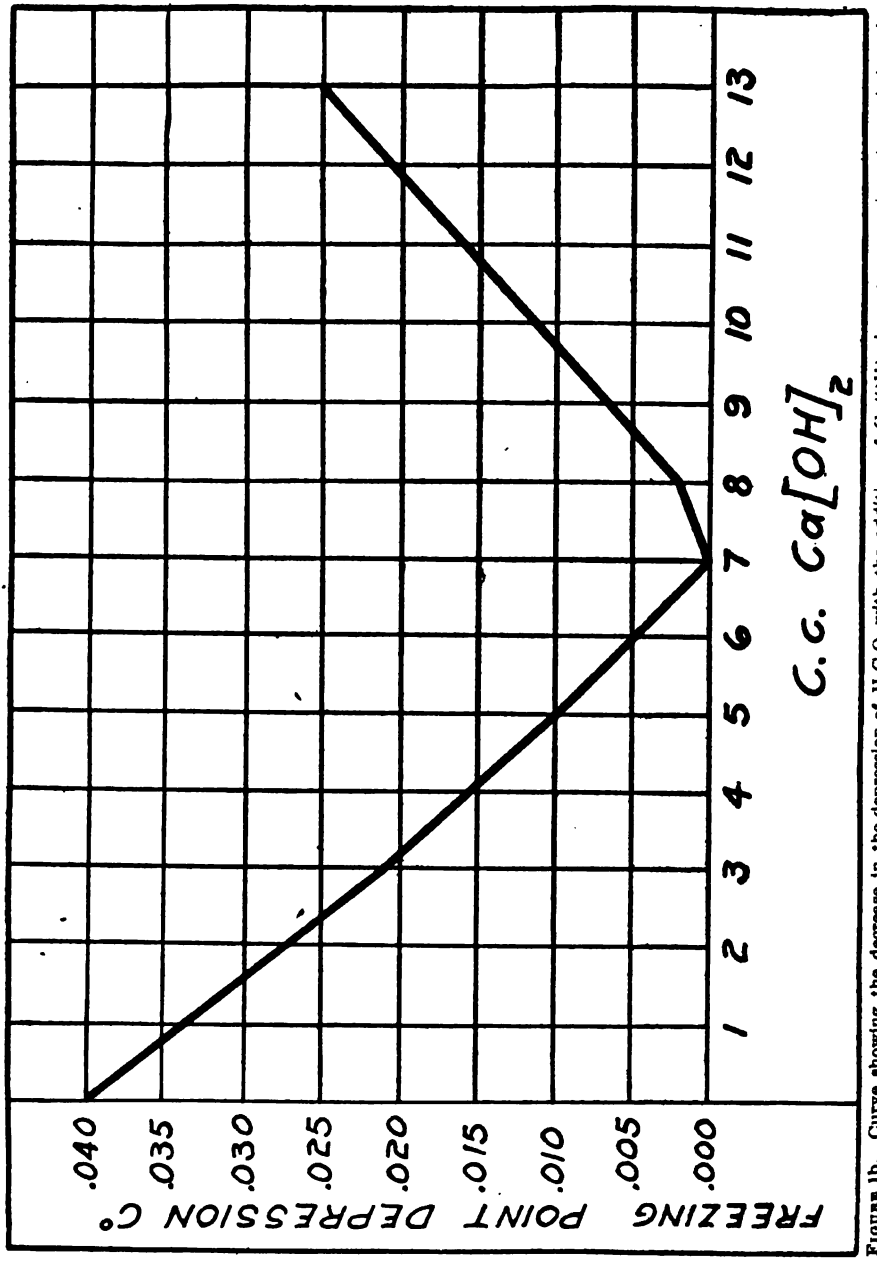


FIGURE 1b. Curve showing the decrease in the depression of $H_2C_2O_4$ with the addition of $Ca(OH)_2$ down to a certain point and then the increase with further addition of $Ca(OH)_2$.

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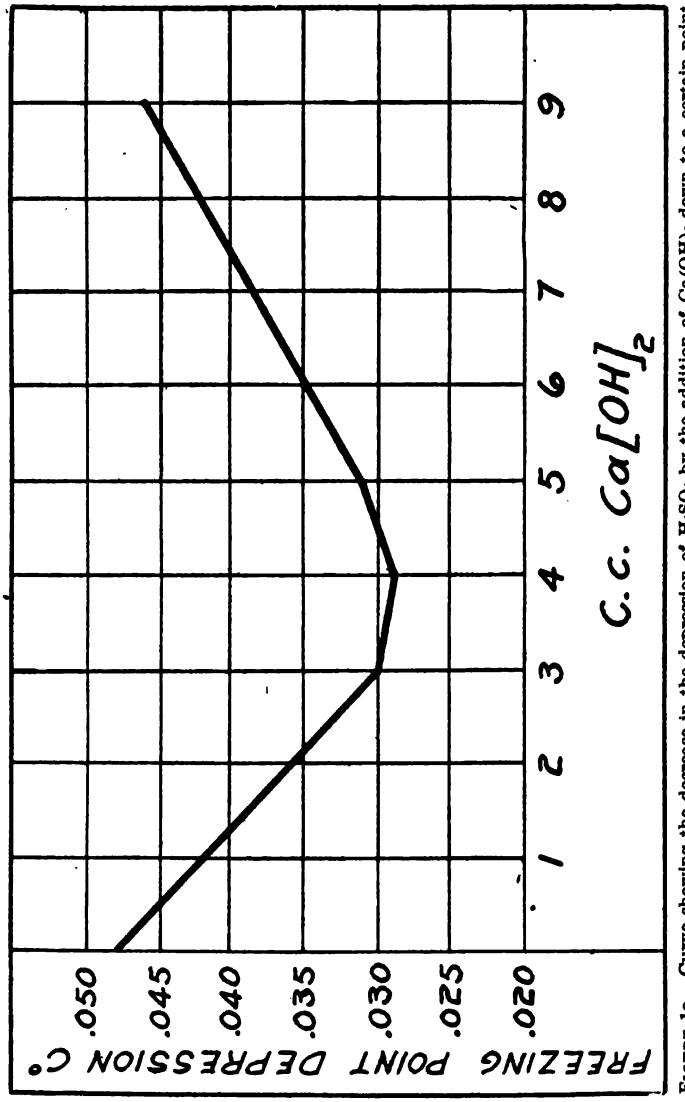


FIGURE 1c. Curve showing the decrease in the depression of $H_2SO_4$ by the addition of $Ca(OH)_2$ down to a certain point and then the increase with further addition of $Ca(OH)_2$.



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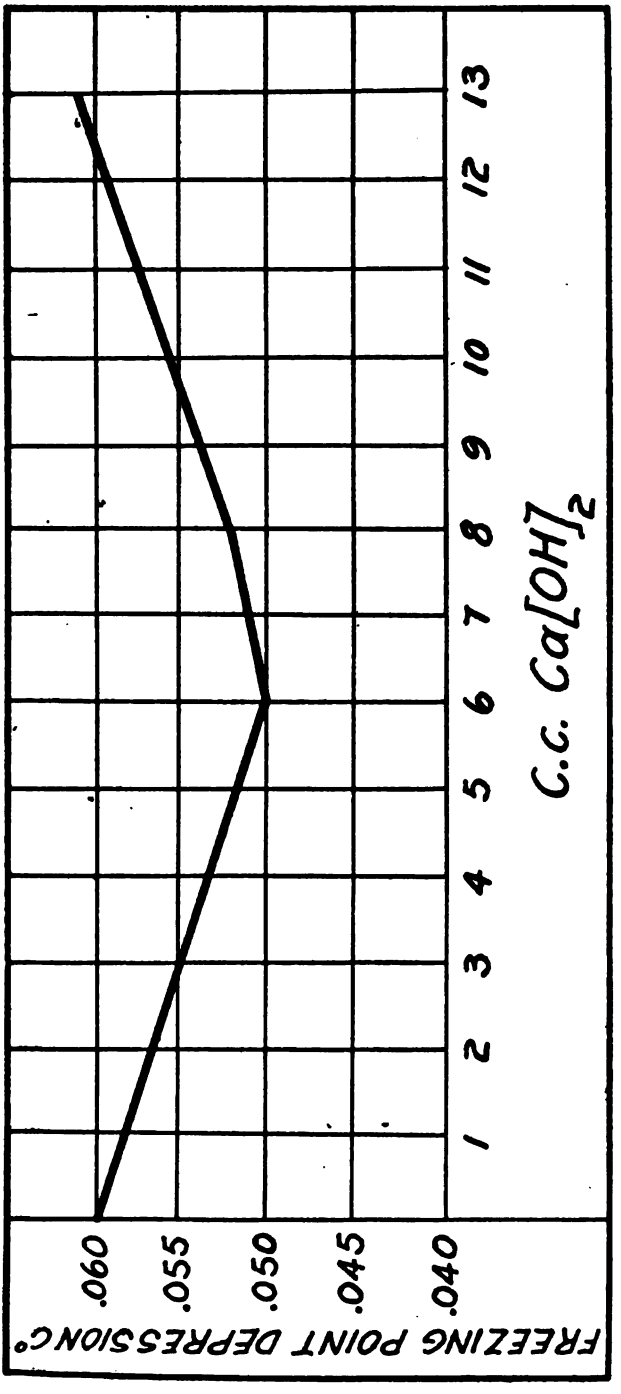


FIGURE 1d. Curve showing the decrease in the depression of $Al_2(NO_3)_6$ by the addition of $Ca(OH)_2$ down to a certain point and then the increase with further addition of $Ca(OH)_2$.

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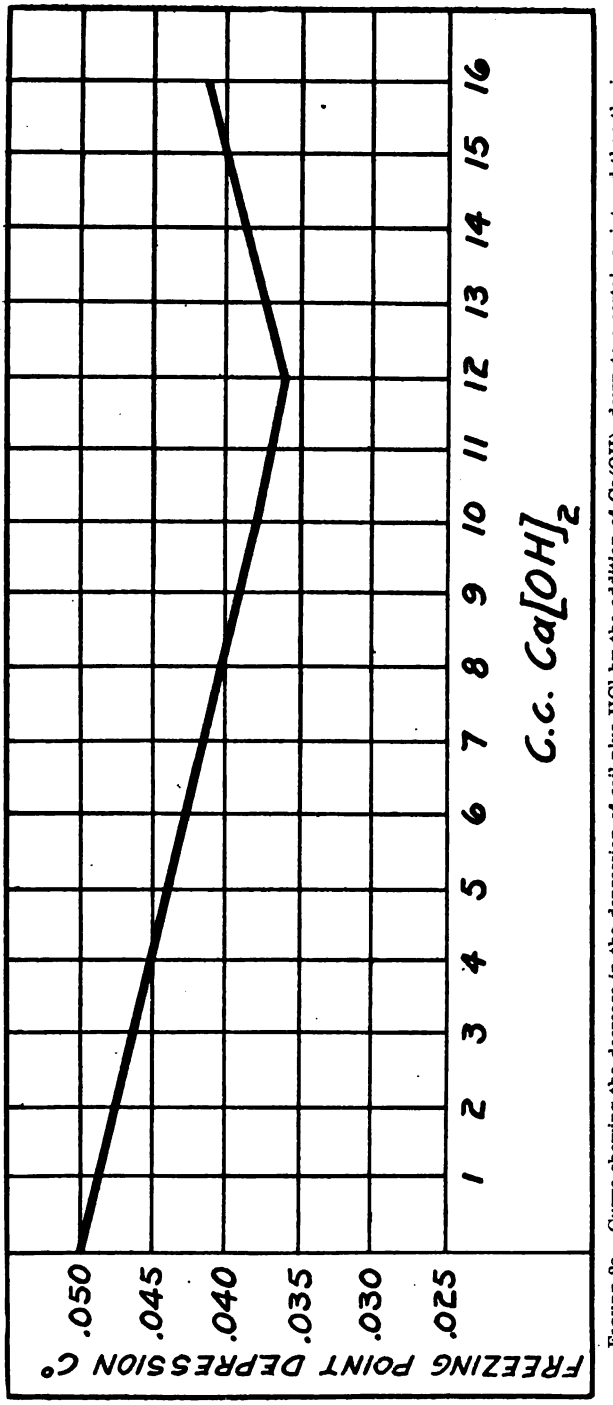


FIGURE 2a.—Curve showing the decrease in the depression of soil plus HCl by the addition of $Ca(OH)_2$ down to a certain point and then the increase with further addition of $Ca(OH)_2$.

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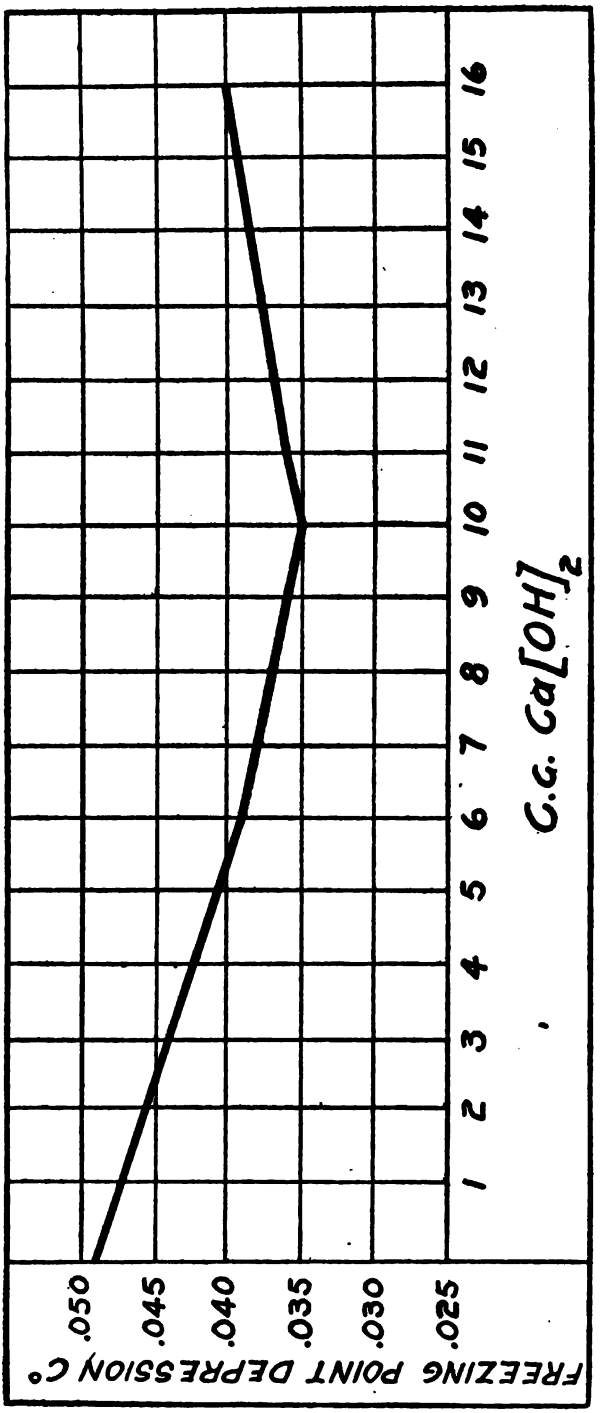


FIGURE 2b. Curve showing the decrease in the depression of soil plus $Al_2(NO_3)_6$ by the addition of $Ca(OH)_2$ down to a certain point and the increase with further addition of $Ca(OH)_2$.

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TABLE 2. THE FREEZING POINT DEPRESSION OF SOILS TO WHICH WERE ADDED HCl AND $Al_2(NO_3)_3$ AND TITRATED WITH $Ca(OH)_2$.

| Reagents. | Depression. |
|---|---|
| Soil plus HCl | .050°C |
| plus 10 c. c. $Ca(OH)_2$ | .038 |
| plus 2 c. c. $Ca(OH)_2$ | .036 |
| plus 2 c. c. $Ca(OH)_2$ | .039 |
| plus 2 c. c. $Ca(OH)_2$ | .041 |
| Soil plus $Al_2(NO_3)_3$ | .049°C |
| plus 6 c. c. $Ca(OH)_2$ | .039 |
| plus 4 c. c. $Ca(OH)_2$ | .035 |
| plus 1 c. c. $Ca(OH)_2$ | .036 |
| plus 5 c. c. $Ca(OH)_2$ | .040 |

It will at once be seen that when a soil is treated with an acid or acid salt and then titrated with $Ca(OH)_2$ almost exactly the same general results are obtained as when the acid and acid salt are titrated alone. The main difference being that the lower part of the curves of the soils is not so sharply pointed as that of the solution. Occasionally the lower part of the curves of the soils may be slightly flattened.

The above type of curve is designated for convenience, and will be referred to throughout this paper as *an acid curve.*

The second principle, that if a soil does not contain a free acid or acid salt but possesses an absorptive power for $Ca(OH)_2$ the freezing point depression will remain the same as more and more of $Ca(OH)_2$ is added to the soil, until the absorptive power is satisfied and then it will commence to rise with further addition of $Ca(OH)_2$ was established in natural soils. The procedure consisted of adding 10 c. c. of water to 2 grams of soil and then titrating with $Ca(OH)_2$ in the same manner as above. Table 3, with its accompanying figures 3a and 3b contain the general type of results obtained.

TABLE 3. THE FREEZING POINT DEPRESSION OF SOILS TO WHICH WERE ADDED DIFFERENT AMOUNTS OF $Ca(OH)_2$.

| Reagents. | Depression. |
|---|---|
| 2 gm. Soil No. 1 plus 10 c. c. water | .010°C |
| plus 5 cc. $Ca(OH)_2$ | .010 |
| plus 3 cc. $Ca(OH)_2$ | .010 |
| plus 1 cc. $Ca(OH)_2$ | .010 |
| plus 1 cc. $Ca(OH)_2$ | .012 |
| plus 3 cc. $Ca(OH)_2$ | .020 |
| 2 gm. Soil No. 2 plus 10 c. c. water | .011°C |
| plus 5 cc. $Ca(OH)_2$ | .011 |
| plus 1 cc. $Ca(OH)_2$ | .012 |
| plus 2 cc. $Ca(OH)_2$ | .021 |

It becomes immediately evident that the second principle, namely that when a soil does not contain a free acid or acid salt but possesses an absorptive power for $Ca(OH)_2$ the depression remains constant as more and more of the $Ca(OH)_2$ is added until the absorptive power is satisfied, and then it begins to increase with further addition of $Ca(OH)_2$, is fully confirmed by the above data.

The curve typifying the second principle is designated for convenience, and will be referred to throughout this paper as *an absorption curve.*

If a soil possesses both an acid and an absorptive power, the curve obtained will be similar to that shown in Figure 2 which is an acid curve.

There still remains the third principle to illustrate, namely, that when a soil is alkaline or already saturated with bases, the freezing point depression will commence to rise almost immediately upon adding a small amount of $Ca(OH)_2$. A typical example of this principle is afforded in

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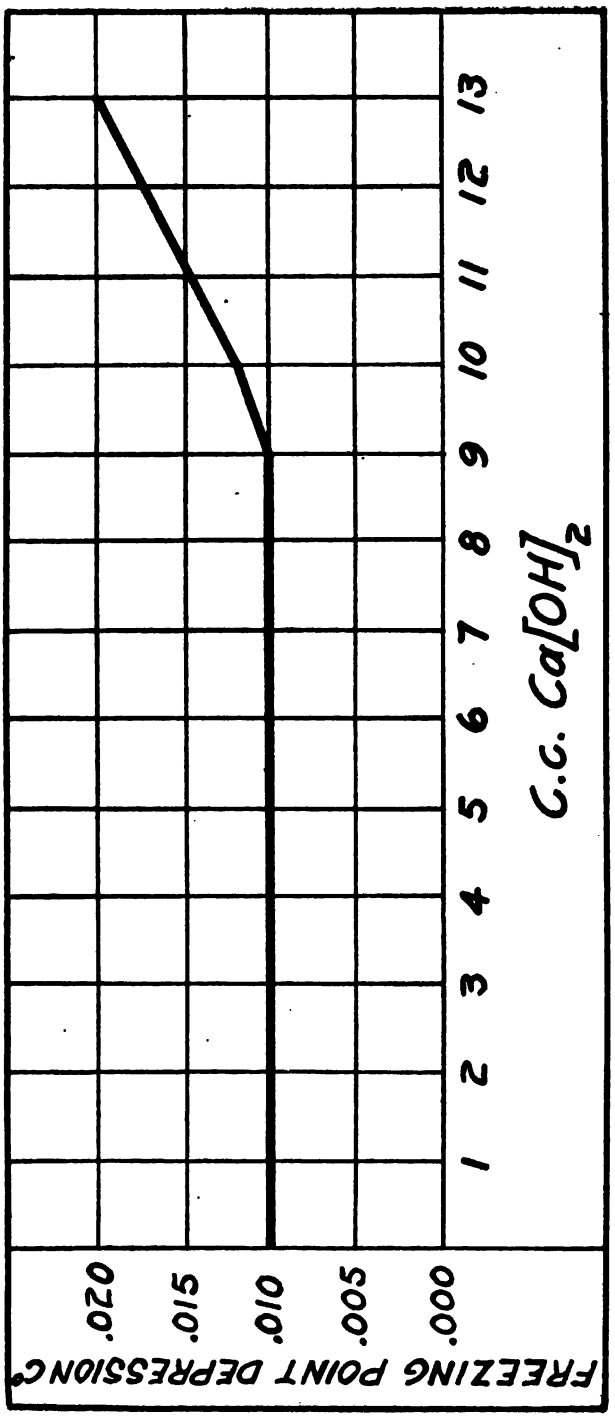


FIGURE 3a. Curve showing the constancy of the depression of soils by successive addition of $Ca(OH)_2$ up to a certain point, then the increase with further addition of $Ca(OH)_2$

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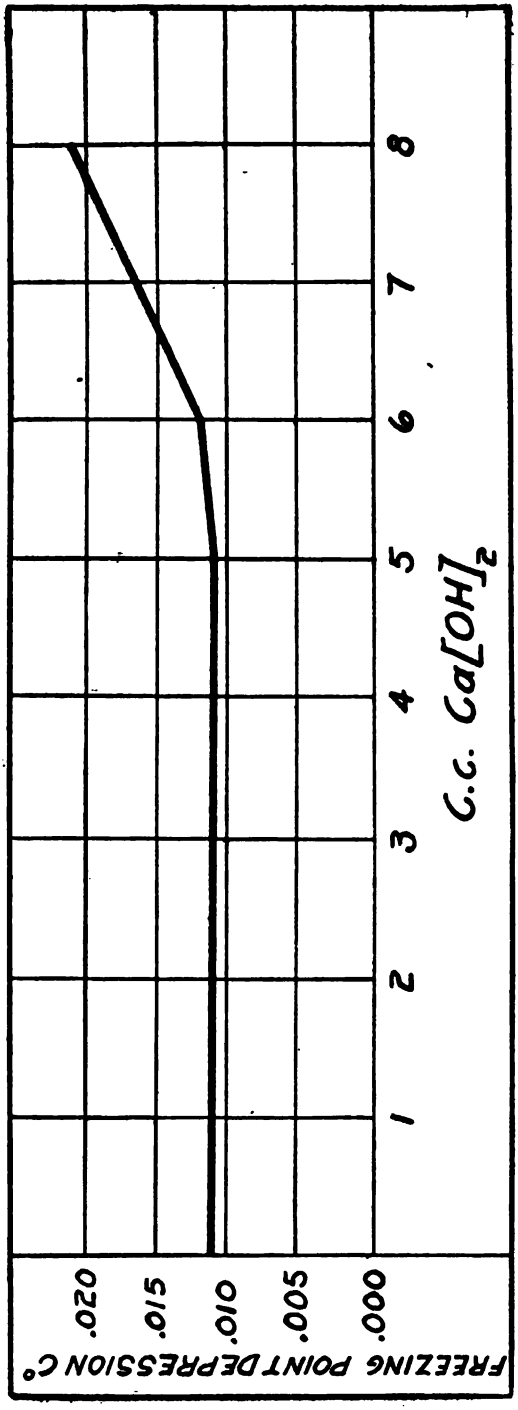


FIGURE 3b. Curve showing the constancy of the depression of soils by the successive addition of $Ca(OH)_2$ up to a certain point and then the increase with further addition of $Ca(OH)_2$.

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Table 4 and in the accompanying Figure 4. The numerical data were obtained by treating a soil with an excess of KOH and then titrating with $Ca(OH)_2$ in the usual manner.

TABLE 4. THE FREEZING POINT DEPRESSION OF ALKALINE SOIL TO WHICH WAS ADDED $Ca(OH)_2$.

| Reagents. | Depression. |
|---|---|
| 2 gm. soil plus 10 c. c. water | .015°C |
| plus 1 c. c. $Ca(OH)_2$ | .016 |
| plus 2 c. c. $Ca(OH)_2$ | .024 |

The third principle, therefore, is also established by the preceding data. As will be noticed the depression commenced to rise when only 1 c. c. $Ca(OH)_2$ was added, while before this soil was saturated with KOH it required 9 c. c. of $Ca(OH)_2$ of the same strength before the freezing point depression started to rise.

The curve illustrating the third principle is named and will be referred to as the *alkaline or no-lime-requirement curve.*

Going back for a moment to the first type of curve, the acid curve, the question may be raised, may there not be other substances, besides acids and acid salts, which upon reacting with $Ca(OH)_2$, give the same type of curve? Before attempting to answer this question it is necessary first to consider the cause or causes which produce this type of curve.

According to the ionic theory, acids, bases, and salts or electrolytes, tend to break up or dissociate into ions, and the degree of dissociation varies markedly in the various electrolytes. Besides other properties, each ion causes the same amount of depression of the freezing point as a molecule. The larger the number of ions, therefore, there is present in a solution, the greater will be the freezing point depression. Since the various acids, bases, and salts, dissociate differently at the same molecular concentration their depression of the freezing point will necessarily be different.

In the light of the ionic theory, therefore, the reason for the gradual decrease in the depression of the acids and acid salts upon adding to them various amounts of $Ca(OH)_2$ until the neutralization point is reached and then commences to rise with further addition of the hydrate, becomes at once clear and self-evident. Thus, for instance, consider the case of HCl. This acid at the concentration employed possesses a definite degree of dissociation and hence also a freezing point depression. Upon the addition of a small amount of $Ca(OH)_2$ part of the acid combines with the Ca to form $CaCl_2$. The $CaCl_2$ evidently has a lower degree of dissociation than that of either HCl and $Ca(OH)_2$, and consequently the lowering of the freezing point is decreased. This decrease continues until all the acid is completely neutralized and there is present only $CaCl_2$ and $H_2O$. Since the degree of dissociation of CaCl is less than that of either HCl and $Ca(OH)_2$ the minimum lowering of the freezing point is registered at the point of neutralization. Upon further addition of $Ca(OH)_2$ after the neutralization is reached, the $Ca(OH)_2$ remains in solution, and since it possesses a greater degree of dissociation than the $CaCl_2$, causes an ascent in the depression.

Any salt, therefore, formed by the reaction between any acid and any base will give the same type of curve as that between HCl and $Ca(OH)_2$ provided the salt thus formed has a lower degree of dissociation than either of the acid and base. It might be stated in this connection that

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all the acids employed in this investigation, which included only HCl, $HNO_3$, $H_2SO_4$, and $H_2C_2O_4$, gave the usual acid curve upon being titrated with $Ca(OH)_2$, NaOH, and KOH; the $NH_4OH$, however, failed to give the characteristic acid curve, at least in any pronounced form.

Besides the factor of dissociation, there is still a second factor which might produce the acid curve, and that is the insolubility of the product formed from the reaction between the acid and the base. Thus, for instance, take the case of $CaH_4(PO_4)_2$ and $H_2C_2O_4$. Upon the addition of $Ca(OH)_2$ the Ca combines with $CaH_4(PO_4)_2$ and $H_2C_2O_4$ to form $Ca_3(PO_4)$ and $CaC_2O_4$ which are quite insoluble. As long, therefore, as the reaction is not completed the depression will diminish with the increased addition of $Ca(OH)_2$ but as soon as sufficient $Ca(OH)_2$ has been added to com-

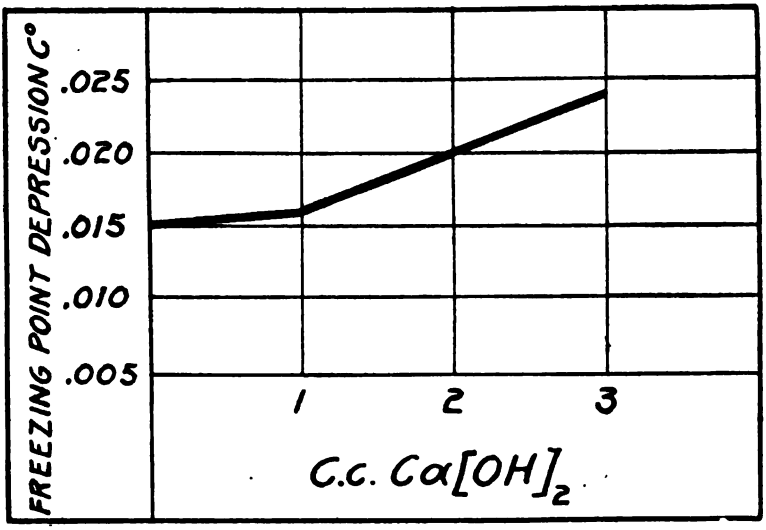


FIGURE 4. Curve showing the almost immediate rise in the depression of alkaline soils upon adding $Ca(OH)_2$

plete the reaction, then there will occur a minimum depression; beyond this point the depression will commence to rise with further addition of $Ca(OH)_2$.

The question already raised, therefore, namely, may not substances other than acids and acid salts react with $Ca(OH)_2$ to produce a curve similar to the acid curve, can now be answered. It should be declared at once, however, that while this might be so with certain compounds, yet a large number of compounds have been employed for the purpose of testing out this point and in no case was there an acid curve obtained.

On the other hand it has been found that certain compounds which are neither acids nor bases may react between themselves to form other compounds and thus yield a curve similar to the acid curve. A most striking case of this kind may be cited the reaction between $BaCl_2$ and $Ag_2SO_4$. If $Ag_2SO_4$ is treated with $BaCl_2$ the freezing point depression decreases similarly to that when HCl is titrated with $Ca(OH)_2$ until the reaction is complete where a minimum depression is registered and then the depression commences to rise with further addition of $BaCl_2$.

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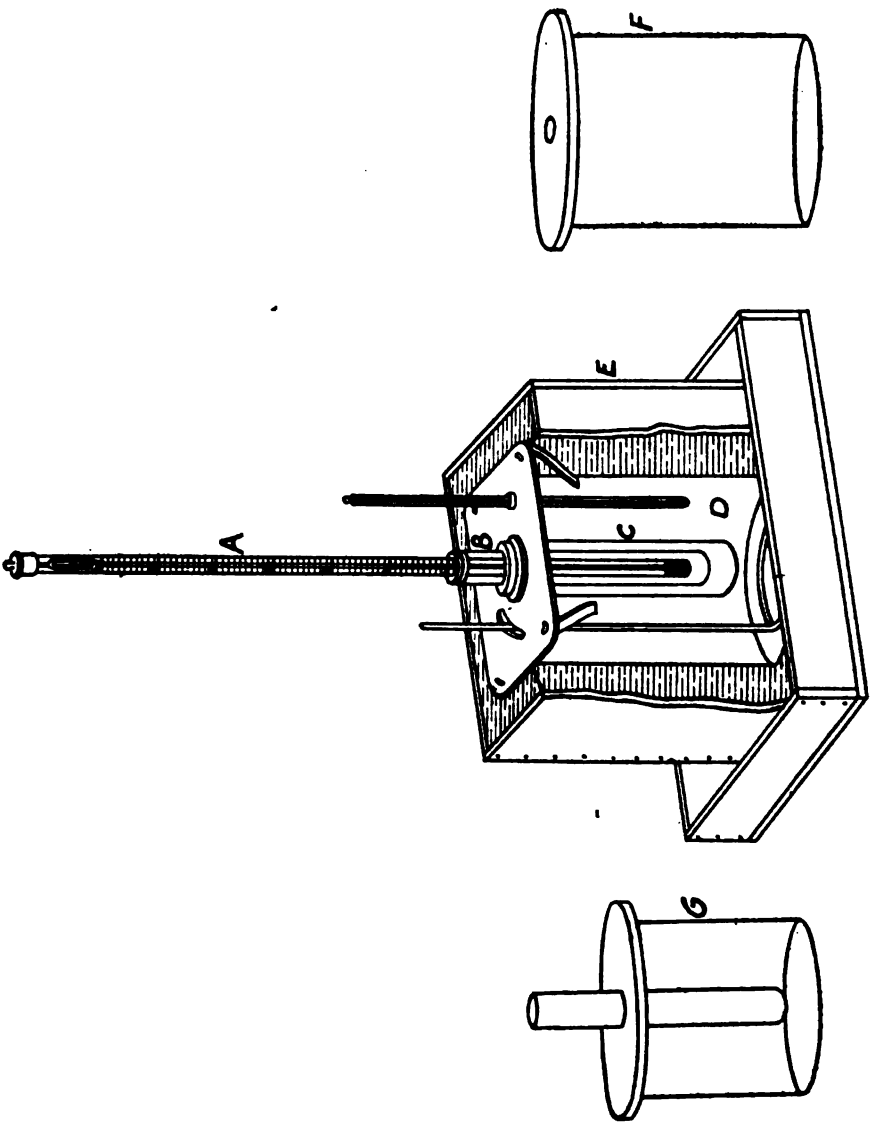


FIGURE 5. Apparatus for determining the lime requirement of soils.

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The explanation of this penomenon is self-evident. The $Ag_2SO_4$ reacts with $BaCl_2$ to form $BaSO_4$ and AgCl. Both of these salts being almost insoluble cause a minimum depression when the reaction is complete. Upon further addition of $BaCl_2$ after the complete precipitation of $BaSO_4$ and AgCl, the lowering of the freezing point rises because the $BaCl_2$ remains in solution.

So while it could be stated as a very general rule that if a soil contains a free soluble acid or acid salt it will always give an acid curve when it is titrated with $Ca(OH)_2$ yet it is possible sometimes to obtain an acid curve which is not due to an acid or acid salt. Such a case, however, will probably be very rare.

In the foregoing exposition an attempt has been made to indicate briefly the underlying principles governing the freezing point method for determining the nature of acidity and lime requirement of soils. It has been seen that three distinct types of curves are obtained, and each one of these curves signifies a definite phenomenon. Next a description of the procedure involved in the method, the presentation of the detailed results obtained, and the possible explanations therefor, are in order.

## DESCRIPTION OF THE METHOD AND PROCEDURE.

For determining the nature of soil acidity and lime requirement of soils by the freezing point method, the Beckmann apparatus was employed with certain modifications. The complete set of apparatus used is shown in Figure 5. It is composed of a Beckmann thermometer A, a glass tube B which contains the soil, a larger tube C which acts as an air jacket, a battery jar D which contains the cooling mixture, composed of crushed ice and NaCl, and a wooden box E in which the battery jar is placed and surrounded with poor heat conducting material to prevent rapid radiation of the cooling system. The glass tube B is 1 inch in diameter and 9 inches long, while glass tube C is 1.5 inches in diameter and 6 inches long. Vessels F and G act as accessories to the above main apparatus. Vessel F contains a cooling mixture of the same or different temperature as that in the battery jar D, and its cooling mixture serves the purpose of taking off more rapidly the initial heat of the soil mass by bringing the tube containing the soil mass into intimate contact with it. Vessel G acts simply as a stand for the thermometer when it is taken out of the glass tube B for preparing another soil sample or for adding $Ca(OH)_2$ to the soils at the end of each freezing point determination. In this vessel there is a glass tube of the same dimensions as the glass tube B. By cleaning this tube at the beginning of each experiment it becomes unnecessary to clean the bulb of the thermometer every time the latter is taken out of the soil tube to add $Ca(OH)_2$ to the soil. Near to this set of apparatus are kept burettes attached to bottles of distilled water and $Ca(OH)_2$ stock solution, or to bottles containing any other reagent employed.

For determining the lime requirement of a soil the following procedure was finally adopted: First the freezing point of pure distilled water was determined and this point was used as a standard for ascertaining the

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freezing point depression of soils. Then 2 grams of soil were weighed out on a chemical balance and placed into the soil tube B and added to it 10 c. c. of distilled water. The thermometer was inserted into the tube and was so arranged that the bulb was close to the bottom of the tube and entirely covered with the soil mixture. By holding the tube with one hand and the thermometer with the other the soil mixture was stirred for about a minute by gently moving the thermometer. The tube then was placed directly into the cooling mixture contained in the vessel F and by continuously stirring the soil mass with a gentle move of the thermometer, the temperature fell very rapidly. The agitation was continued until the temperature reached the freezing point of water when it was stopped and the soil was allowed to cool undisturbed until it was supercooled to about 1.0° C. below the freezing point of water and then the tube was placed in the air jacket C of the main cooling bath and the soil mass again stirred. The soil generally commenced to solidify at once and the temperature to rise very rapidly to the proper freezing point. Before the final reading was taken, the soil mixture was thoroughly mixed by moving the thermometer. The thermometer then was set so its bulb stood in the center of the tube and did not touch the walls, tapped with the finger a few times and then the final reading recorded. The tube then was taken out of the air jacket, the thermometer placed in the stand G, and a definite quantity of $Ca(OH)_2$ was added to the soil. The thermometer was placed back into the soil, the mixture stirred for about a minute, and the process of freezing was repeated as before. The process of freezing, then adding $Ca(OH)_2$ to the soil, and refreezing was continued until the maximum lime requirement of the soil was attained, which was indicated by a change in the reading of the thermometer and hence of the freezing point depression.

In order to reduce the number of determinations made and thereby cut down on the length of time, large quantities of $Ca(OH)_2$ were first added. The method which proved most convenient consisted of adding to the soil first 5 c. c. of N/25 $Ca(OH)_2$. If the depression of the soil was still the same as before or less, then 5 c. c. more of $Ca(OH)_2$ was added. If the freezing point depression at the end of the third determination was greater than that of the preceding that indicated that the maximum lime requirement of the soil had been attained and surpassed, i. e., an excess of lime had been added. From the difference in the depression between the second and third determination it could be easily estimated what would be the approximate lime requirement, and with this knowledge as a guide the exact quantity was determined in a second sample of soil. Thus, for example, supposing that 2 grams of soil plus 10 c. c. of water gave a depression of .010° C. Adding 5 c. c. of N/25 $Ca(OH)_2$ to the mixture the depression still remained at .010° C. Adding 5 c. c. more of $Ca(OH)_2$ the depression changed to .012° C., or a difference of .002° C. The lime requirement of this soil, therefore, lay between 5 and 10 c. c. of $Ca(OH)_2$; but does it lie nearer the 5 or 10 c. c.? Information concerning this point could be obtained by knowing the depression of 5 and 10 c. c. of N/25 $Ca(OH)_2$ diluted in 20 c. c. of distilled water—the amount which had been added to the soil. Supposing the depression of 5 c. c. of N/25 $Ca(OH)_2$ in 20 c. c. of distilled water was .020° C., and 10 c. c. in 20 c. c. of water was .035° C. From these figures it could be readily judged that the true lime requirement

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was closer to the 10 c. c. than to the 5 c. c. of $Ca(OH)_2$ since the change in the depression was only .002° C. A second sample of soil therefore, was taken and instead of adding 5 c. c. of $Ca(OH)_2$ at first 8 c. c. were added and then the additional amounts were added in portions of 1 c. c. in order to obtain the accurate value. If a soil, however, in 2 gram portion, required only 2 c. c. of $Ca(OH)_2$ and were added to it at first 5 c. c., the depression in the second determination would be far greater than that of the soil plus water alone. By applying the same principle as above as to whether the true lime requirement lay closer to 2 or 5 c. c. the exact amount could be determined in a second sample of soil. After one is accustomed to the method, however, he can estimate accurately almost down to 0.5 c. c. without having to employ a second sample of soil.

From the above detailed description of the procedure of the method, it might appear that the method is very complicated, tedious, and time-consuming. Fortunately none of these objections is applicable to it. On the contrary, the method is very simple, extremely rapid, and quite accurate.

As to its simplicity, it must have already been seen from the description that there is practically no procedure in the method which requires an unusual amount of skill or technique. Anyone who has never performed freezing point determinations might imagine that the method is complicated but those who have made such studies will readily admit the simplicity of operation of the method.

Probably one of the most favorable virtues of this method is its rapidity of execution. As it is now developed, the freezing point method can determine the lime requirement of a soil from 10 to 15 minutes if a duplication is not necessary. It has determined the lime requirement of many soils in less than 10 minutes. This exceeding rapidity of execution lies in the fact that by bringing the tube containing the soil mixture in direct contact with the cooling mixture and keeping the soil mixture stirred with the thermometer, the temperature falls very rapidly, and the desired super-cooling is attained in a very few minutes,—as contrasted with the long time that it takes if the soil were cooled in the air jacket.

At this point the question may be raised as to the value and accuracy of the method for determining the lime requirement of soils in such an exceedingly short period of time, since the reaction between the $Ca(OH)_2$ and the soil may not be completed in that short period. It must be declared at once that this particular point was subjected to a thorough examination, and the results obtained have led to the interesting conclusion that the reaction between the $Ca(OH)_2$ and the soil, under the condition in which the experiments are performed, is exceedingly rapid if not almost instantaneous. Many experiments were performed wherein the soils were treated with slightly larger amounts of lime than they required, as determined during the short period of the operation, and allowed to stand for 6 to 24 hours. At the end of these periods the freezing point depression showed that the soils did not take up any more lime.

The remarkable rapidity of the completion of the reaction between the soil and $Ca(OH)_2$ is supported by other experiments which the writer has performed; as well as the observations of other investigators. In

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performing experiments, for instance, by the freezing point method to determine the effect of application of soluble chemical compounds upon the concentration of the soil solution, it was found that, with few exceptions, the magnitude of the concentration or depression produced, immediately after the salt solution was added to the soil and at the end of 24 hours, was practically the same.

In studying the absorption of the base of different salts by the soil, various investigators have noticed that the reaction is very rapid. Especially interesting in this connection is the work of Gedroiz[7] upon the speed of exchange reaction in soils. Gedroiz found that the Ca could be replaced from the soil by $NH_4$ and Na of the $NH_4Cl$ and NaCl salt solutions almost immediately.

From all these evidences, then, it might be accepted as an established fact that the reaction between the soil and $Ca(OH)_2$ is completed very rapidly if not almost instantaneously, and that practically no error enters in the results from this source.

Besides its simplicity and exceeding rapidity, the freezing point method appears to be also quite accurate, at least from the practical standpoint, in determining the lime requirement of soils. The accuracy seems to vary directly with the lime requirement. If the soil requires about 10,000 pounds CaO per 2,000,000 pounds of soil there is probably an error of about 1,000 pounds CaO. If on the other hand, the soil requires only about 1,000 pounds of CaO per acre the error is probably about 200 or 300 pounds. The reason that the total error is greater when the lime requirement is high is that the volume of water present is large and the depression caused by 1 c. c. of N/25 $Ca(OH)_2$ for instance, is small as compared to that when the volume of water is less. Since the thermometer cannot be depended upon to read accurately, closer than .002° C. it is easier to make a greater total error, although a smaller percentage of error, in the greater lime requirement than in the small.

If a larger amount of soil were used doubtless the percentage of error in both cases would be greatly decreased. By using only 2 grams of soil an error of only 1 c. c. of N/25 $Ca(OH)_2$ is equivalent to 1,121.8 pounds of CaO in 2,000,000 pounds of soil. The reason that a larger amount of soil is not used is that the concentration of the $Ca(OH)_2$ solution cannot be increased in water above twenty-fifth normality. Consequently, it is necessary to add a large amount of the sclution of this strength to the soils possessing a high lime requirement, and the soil tube being of small volume cannot hold all the mass if larger amounts of soil were used. Of course a tube of larger volume could be employed but this may not be advisable.

Mention has already been made that it is advisable to use in the first determinations large amounts of $Ca(OH)_2$ in order to obtain the limits more quickly, and if necessary to employ smaller quantities in a second set of determinations to obtain the exact amount of $Ca(OH)_2$ required. It should also be stated, however, that it is not advisable to add less than 1 c. c. of $Ca(OH)_2$ in the case of soils which require a large amount of lime; in the case of soils, however, which take up about 1,000 pounds CaO to the acre, less than 1 c. c. might be added each time. The reason for not adding less than 1 c. c. to the soils which possess a high lime requirement becomes evident from what has already been said. In the

(7) Russ. J. f. Expt. Landw. Vol. 15. No. 3, 1914.

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first place, the thermometer cannot be depended upon to read accurately closr than .002° C., and in the second place, less than 1 c. c. of N/25 $Ca(OH)_2$ in a large volume of water produces such a small depression that it might not be detected. It is just as accurate, therefore, to add 1 c. c. portions and estimate the tenths, using the magnitude of the depression as a guide.

Finally, the sources of error that might arise from the thermometer and the cooling bath should be mentioned. It has been found that the reading and hence the standardization of the thermometer will suddenly change. This does not happen always, but it does occur occasionally. If the change should occur during a series of titrations of a single soil, and the determination is not checked by a second sample of soil, wrong results will of course be obtained. No definite explanation can be offered for this sudden change of the thermometer. It should be stated, however, that in spite of this occasional uncertain change the Beckmann thermometer is ideally adapted for the determination of the lime requirement of soils, because its zero point is automatically determined every 10 or 15 minutes and for every soil sample. Furthermore, after one is accustomed to the character of the results he can generally detect any change in the thermometer that has taken place. It might be stated in passing that an instrument which is far more accurate and exceedingly more sensitive than the Beckmann thermometer is the thermo-element. A thermo-element can be readily made to read to .0001° C., or ten times more sensitive than the Beckmann thermometer. This instrument, however, is not very convenient to use.

For the determination of the lime requirement of soils by the freezing point method it has been found essential to keep the temperature of the cooling mixture in both vessels about –2° C. If the temperature of the cooling mixture in vessel F, where the soil is first cooled, is greater than –2° C. the soil will commence to solidify before supercooling has taken place, but if it is only about –2° C. the soil will not start to solidify until it is supercooled to about 1° C., and sometimes it can even be gently stirred while it is supercooling.

It might appear that the procedure of stirring the soil mass with the thermometer itself and not employing a regular stirrer, might introduce some error. It is believed, however, that no measurable error arises from this source. The use of the thermometer as a stirrer is of great convenience.

It should be again emphasized that the soil mass must be thoroughly mixed, care must be exercised that the bulb of the thermometer does not touch the walls of the tube, and that the thermometer should be tapped before the final reading is taken.

If the above procedure is carefully followed, it is firmly believed that any scientific man can determine the lime requirement of soils with high accuracy and definiteness.

Having given then a brief exposition of the principles underlying the method, and a rather detailed description of the apparatus and procedure, the presentation of the experimental data obtained, is next in order.

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## EXPERIMENTAL DATA.

### THE LIME REQUIREMENT OF SOILS.

In accordance with the foregoing method, the lime requirement of a large number of soils was determined. Some of these soils were collected at random near the vicinity of this Experiment Station, others came from different parts of this State, and still others were specially obtained from other States. All these soils received no other treatment except drying in the air. In Table 5 there are presented only a few of the soils employed and their respective lime requirement. The lime requirement is expressed in number of c. c. of N/25 $Ca(OH)_2$ taken up by 2 grams of soil and in pounds of CaO in 2,000,000 pounds of soil in the case of the mineral soils, and 1,000,000 pounds in the case of the peats and mucks.

TABLE 5. LIME REQUIREMENT OF SOILS.

| | Soils. | No. c. c. N/25$Ca(OH)_2$ absorbed by 2 grs. Soils. | Pounds CaO in 2,000,000 pounds soil. |
|---|---|---|---|
| 1. | Quartz sand | 0 | 0 |
| 2. | Kaolin | .5 | 560.9 |
| 3. | Heavy silt loam (gray) | 6.0 | 6,730.8 |
| 4. | Heavy silt loam (black) | 9.0 | 10,096.2 |
| 5. | Heavy clay loam (brown) | 8.5 | 9,535.3 |
| 6. | Heavy silt loam (black) | 9.0 | 10,096.2 |
| 7. | Light clay loam (black) | 6.0 | 6,730.8 |
| 8. | Heavy silt loam (black) | 7.5 | 8,412.5 |
| 9. | Light clay loam (gray) | 4.0 | 4,487.2 |
| 10. | Heavy silt loam (gray) | 3.5 | 3,926.3 |
| 11. | Light silt loam (black) | 3.5 | 3,926.3 |
| 12. | Heavy silt loam (gray) | 3.5 | 3,926.3 |
| 13. | Very light silt loam (black) | 3.5 | 3,926.3 |
| 14. | Heavy sandy loam (black) | 6.0 | 6,730.8 |
| 15. | Light silt loam (gray) | 9.0 | 10,096.2 |
| 16. | Coarse sand (brown) | 3.5 | 3,926.3 |
| 17. | Coarse sand (brown) | 6.0 | 6,730.8 |
| 18. | Medium sand (gray) | 1.0 | 1,121.8 |
| 19. | Light sandy loam (black) | 2.0 | 2,243.6 |
| 20. | Very fine sandy loam (brown) | 1.5 | 1,682.7 |
| 21. | Heavy sand (brown) | 3.5 | 3,926.3 |
| 22. | Very fine sandy loam (brown) | 4.5 | 5,048.1 |
| 23. | Light silt loam (black) | 2.0 | 2,243.6 |
| 24. | Light silt loam (brown) | 4.0 | 4,487.2 |
| 25. | Light silt loam (brown) | 4.0 | 4,487.2 |
| 26. | Light silt loam (brown) | 4.0 | 4,487.2 |
| 27. | Light silt loam (brown) | 4.0 | 4,487.2 |
| 28. | Peat | 30.0 | 16,827.0 |
| 29. | Peat | 28.0 | 15,705.2 |
| 30. | Peat | 30.0 | 16,827.0 |

An examination of the above table will at once show that the lime requirement of different soils varies greatly, according to the freezing point method, the amounts varying from 0 in the case of pure quartz sand, to 10,096.2 pounds in heavy loams, to 16,827.0 pounds in peats, of

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CaO per acre. It appears that the peats, clay loams and silt loams take up larger amounts of lime than the sands and sandy loams, although in some cases the sands and sandy loams consume as much as the clay loams, and silt loams. Soil No. 17, for instance, is a coarse sand, and its lime requirement is the same as that of heavy silt loam No. 3, which is 6,730.8 pounds CaO. Soils No. 20, 31, and 32 were obtained from the Rhode Island Experiment Station through the kindness of Director Hartwell. All these three soils were considered to be acid. Soil No. 22 refused to produce satisfactory crops, according to Dr. Hartwell. This soil may be classed as very fine sandy loam and yet its lime requirement is very high. Soil No. 15 is a light silt loam and was kindly furnished by Prof. A. J. Patten of this Station. It was considered to be very acid as it turned the blue litmus paper red and showed a large lime requirement by the Veitch method. Soils No. 24, 25, 26 and 27 are light silt loams and were procured from the Pennsylvania Experiment Station plots through the kindness of Prof. J. W. White. All these soils were supposed to be acid. Soils No. 27, 29, and 30 are peats and show a tremendous lime requirement. The amount shown above is based upon 1,000,000 pounds of soil; if it were based upon 2,000,000 pounds as in the case of the mineral soils, it would be twice as large.

In order to see how the above lime requirements obtained by the freezing point method, compared with those by the Veitch method, Prof. A. J. Patten kindly determined the lime requirement of soils No. 3, 4, 15, and 16 by the latter method. These values are contained in Table 6. For direct and convenient comparison the corresponding values indicated by the freezing point method are repeated in this table.

TABLE 6. COMPARISON OF LIME REQUIREMENT OF SOILS BY THE VEITCH AND FREEZING POINT METHODS.

| | Pounds CaO per 2,000,000 lbs. soil. | |
|---|---|---|
| | Freezing point method. | Veitch method. |
| Soil No. 3 | 6,730.8 | 560 |
| Soil No. 4 | 10,096.2 | 0 |
| Soil No. 15 | 10,096.2 | 3,780 |
| Soil No. 16 | 3,926.3 | 1,890 |

It is readily seen that the results yielded by the two methods do not at all agree. The freezing point method indicates a far greater lime requirement of every soil than the Veitch method.

If to any one of the soils contained in Table 5 is added only half of the amount of CaO indicated by the freezing point method, and the ratio of soil to water is 1 to 5, the red litmus paper will immediately or shortly turn blue. This, however, is found to be true even with the Veitch method, and it is a pure case of hydrolysis, as already discussed.

It will now be of interest to ascertain the type of curve that the various soils in Table 5 yield. In Table 7 there are presented the numerical data of a few examples which are typical of the various classes of soil. These results are graphically represented in figures 6a, 6b, 6c and 6d.



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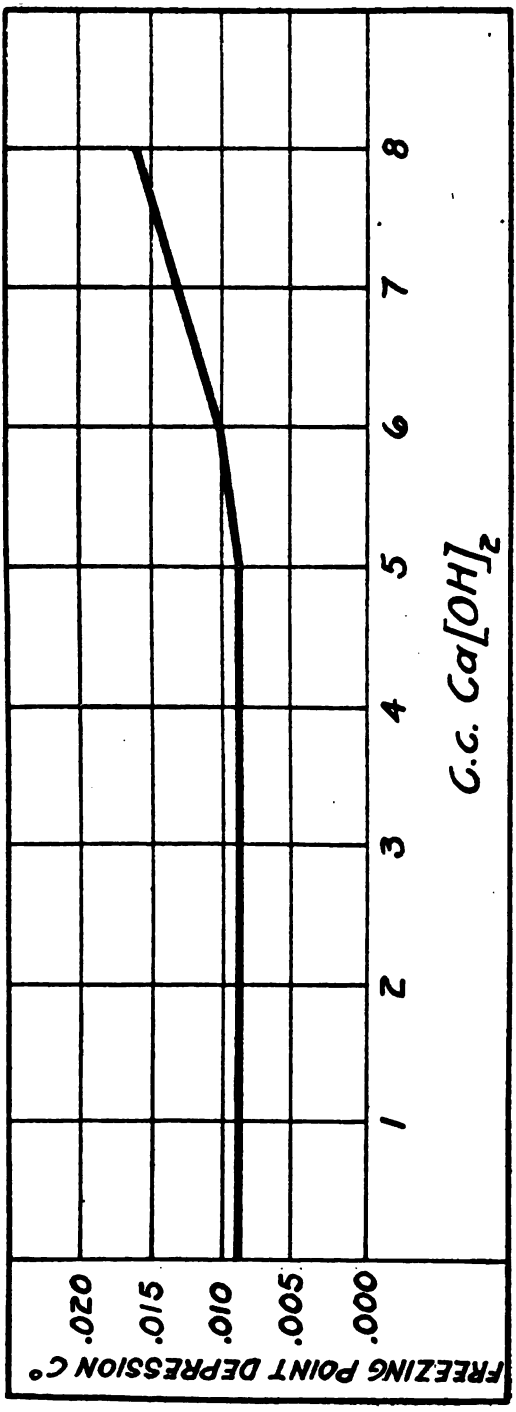


FIGURE 6a. Curve showing the constancy of the depression of mineral soils by the successive addition of $Ca(OH)_2$ up to a certain point and then the increase with further addition of $Ca(OH)_2$.

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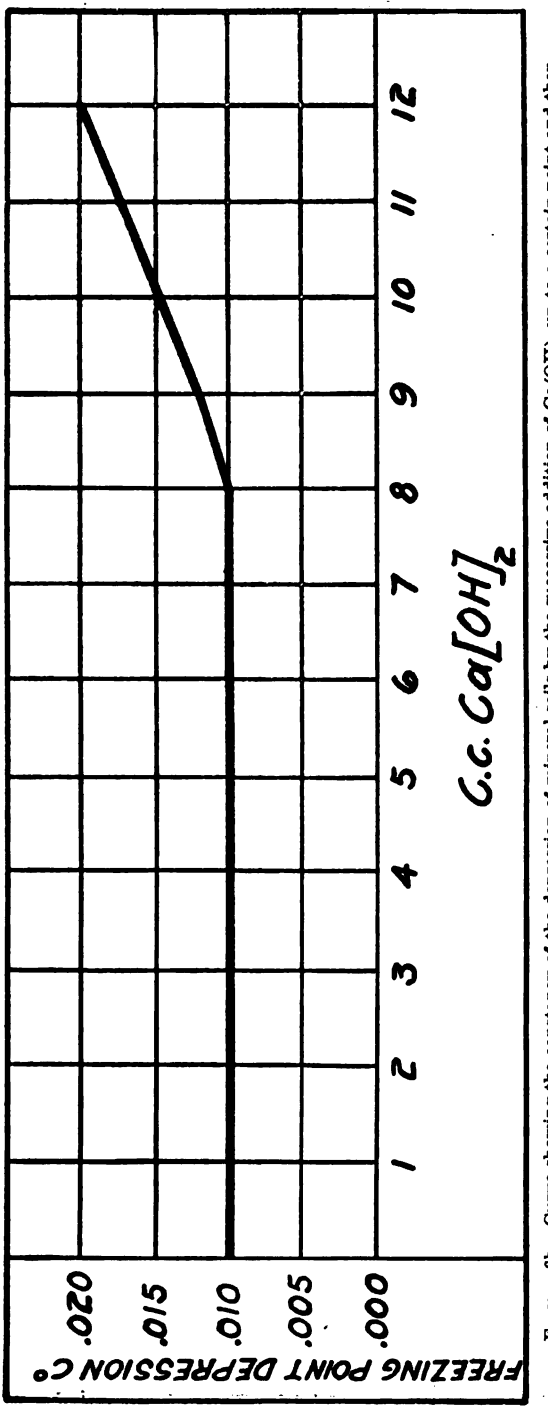


FIGURE 6b. Curve showing the constancy of the depression of mineral soils by the successive addition of $Ca(OH)_2$ up to a certain point and then the increase with the further addition of $Ca(OH)_2$.

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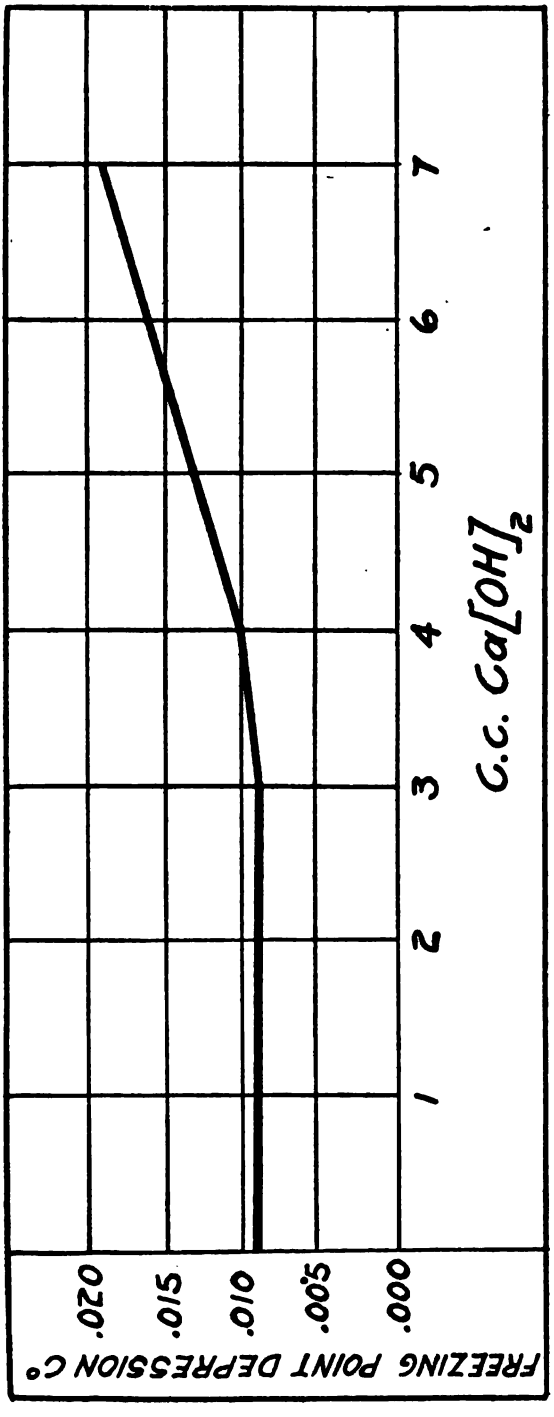


FIGURE 6c. Curve showing the constancy of the depression of mineral soils by the successive addition of $Ca(OH)_2$ up to a certain point and then the increase with the further addition of $Ca(OH)_2$.

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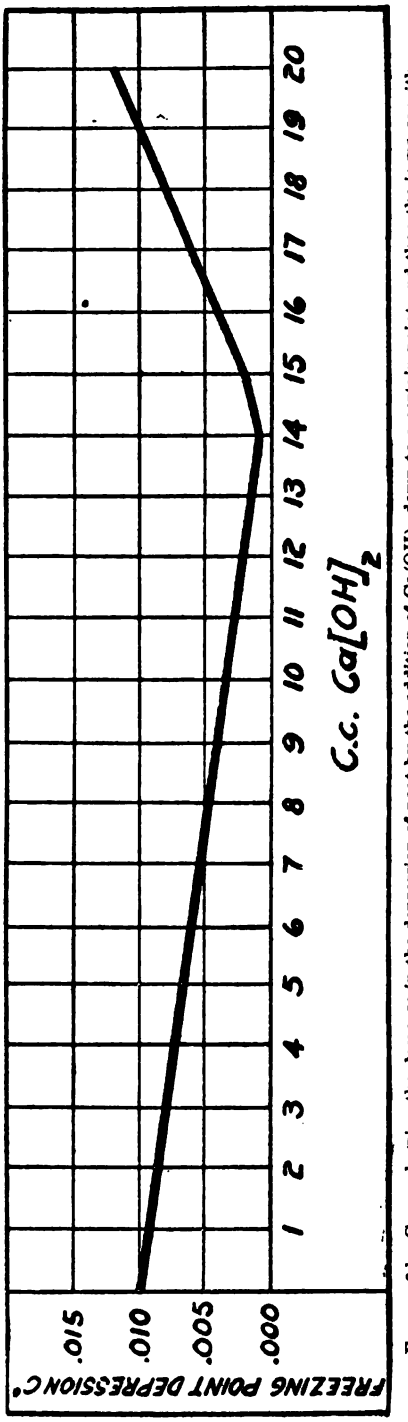


FIGURE 6d. Curve showing the decrease in the depression of peat by the addition of $Ca(OH)_2$ down to a certain point and then the increase with the further addition of $Ca(OH)_2$.

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TABLE 7. THE FREEZING POINT DEPRESSION OF SOILS TO WHICH WERE ADDED VARIOUS QUANTITIES OF $Ca(OH)_2$.

| Reagents. | Depression. |
|---|---|
| 2 gm. Soil No. 3 plus 10 c. c. water | .009°C |
| plus 5 c. c. N/25 $Ca(OH)_2$ | .009 |
| plus 1 c. c. N/25 $Ca(OH)_2$ | .010 |
| plus 2 c. c. N/25 $Ca(OH)_2$ | .016 |
| 2 gm. Soil No. 4 plus 10 c. c. water | .010°C |
| plus 8 c. c. N/25 $Ca(OH)_2$ | .010 |
| plus 1 c. c. N/25 $Ca(OH)_2$ | .012 |
| plus 3 c. c. N/25 $Ca(OH)_2$ | .020 |
| 2 gm. Soil No. 9 plus 10 c. c. water | .009°C |
| plus 3 c. c. N/25 $Ca(OH)_2$ | .009 |
| plus 1 c. c. N/25 $Ca(OH)_2$ | .010 |
| plus 3 c. c. N/25 $Ca(OH)_2$ | .019 |
| 1 gm. Peat No. 30 plus 10 c. c. water | .010°C |
| plus 14 c. c. N/25 $Ca(OH)_2$ | .001 |
| plus 1 c. c. N/25 $Ca(OH)_2$ | .002 |
| plus 5 c. c. N/25 $Ca(OH)_2$ | .012 |

It is clearly evident that both the absorption and acid curves are obtained. It will be noted, however, that only the peats gave an acid curve, while the mineral soils yielded the absorption curve. Since the above examples are presented to typify the general character of curve that all the different soils in their natural condition yielded, then it will at once be inferred that only the peats and mucks yielded the acid curve while the mineral soils gave the absorption curve. Indeed nearly 80 different mineral soils have been tested by the freezing point method both for their lime requirement and nature of their acidity and in no case was an acid curve obtained. This array of soils included some of the most acid soils of the Rhode Island and Pennsylvania experimental plots. On the other hand, most of the peats, which numbered only 15, and collected at random, gave an acid curve.

Although none of the 80 mineral soils tested failed to give an acid curve, it cannot be concluded that universally all mineral soils will act alike. On the contrary there are probably some mineral soils which would give an acid curve, but it is believed that such soils are rare. On the other hand, probably all the mineral soils under humid conditions can be induced, by certain treatments, to give an acid curve, as will be subsequently shown.

The curve yielded by the mineral soils and designated for convenience an absorption curve is of great significance and warrants a thorough consideration. Indeed, this type of curve throws light upon the nature of the acidity of mineral soils, and also upon the theory of exchange of bases in soils.

In the first place this absorption curve shows that the $Ca(OH)_2$ is removed from solution or taken up by the soil as fast as it is added and is rendered inactive as far as the freezing point depression is concerned, until a certain point is reached and then it begins to remain in solution, or if it is still taken up, it replaces something else, most likely another base. Now the substance which uses up the $Ca(OH)_2$ must be in the solid phase and not in the liquid phase, for if it were in the liquid phase the depression would not remain constant. If the substance were in solution it would take part in the depression produced by the soil plus the water. Upon the addition of $Ca(OH)_2$ a reaction would take place. If the reaction resulted in an insoluble product the substance would be removed from the solution and thus decrease the freezing point depression. If, on the other hand, the reaction resulted in a soluble com-

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pound, the depression would vary according to the degree of dissociation of this compound. Again, if the substance were in solution, then the same kind of curve should be obtained if only the soil solution alone was titrated with $Ca(OH)_2$. When the soil extract was titrated with $Ca(OH)_2$ the absorptive curve was not obtained. The type of curve that was obtained, consisted of a no-lime absorption or alkaline curve, i. e., the depression began to rise almost immediately upon the addition of a small amount of $Ca(OH)_2$ to the soil extract.

*Hence the evidences are strongly in favor of the view that the $Ca(OH)_2$ is taken up or absorbed by a substance which is not in solution and does not affect the freezing point depression. Consequently it must be in the solid form.*

The question now is, if the substance which causes the disappearance of the $Ca(OH)_2$ from the solution is solid, what is its chemical and physical composition? An attempt will now be made to answer this question.

As it is well known, the mineral soils consist largely of silica, aluminum, and iron, followed in smaller amounts by calcium, potassium, sodium and magnesium. These elements, together with others, combine to form polysilicates. The mineral constituents of the soil, therefore, consist of salts of polysilicic acids. These polysilicates being salts of weak acids with strong bases hydrolyse upon being dissolved in water, and the products of hydrolysis consist mainly of an unhydrolyzed salt, a base, and an acid. The acid, which consists probably of silicic acid, alumina-silicates, and silica is more or less insoluble. The bases, however, being more soluble, are carried away by the drainage system, or consumed by the plants, or are dissolved by inorganic and organic acids that might temporarily be formed in the soil. The residue left behind, therefore, consists mainly of silica, acid alumino-silicates, and silicic acid. These compounds possessing a high reactivity for $Ca(OH)_2$ will absorb it immediately upon its being offered to them, and combine with it to form calcium silicates. The calcium silicates are difficultly soluble.

Hence, it appears from all evidences, that the substance which causes the disappearance of the $Ca(OH)_2$ from solution consists mainly of silica, acid alumino-silicates, and silicic acid. This view is strongly supported by the investigation of McIntire, Willis and Hardy[8]. These investigators in conducting a study to determine the factors influencing the lime requirement determinations, found that when different soils were treated with large amounts of $CaCO_3$ and $MgCO_3$, these compounds were soon decomposed by the silica, acid silicates and titanium oxide, the $CO_2$ being dissipated, and the Ca and Mg radicals combined with the above acids to form calcium, and magnesium silicates and calcium and magnesium titanate.

On the other hand, these silica, acid silicates, and silicic acid, must be in some particular physical form, probably in the hydrated and colloidal condition, otherwise they do not seem to show any reactivity towards the $Ca(OH)_2$. Thus, for instance, quartz sand both in medium size and in extremely fine powdered form takes up practically no $Ca(OH)_2$. Again, any of the mineral soils which shows a very high lime requirement absorbs practically no $Ca(OH)_2$ after it is burned.

While the absorption of the $Ca(OH)_2$ may be attributed mainly to the

(8) Univ. Tenn. Agr. Expt. Sta. Bull. 107. 1914.

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colloidal hydrated silica, acid alumino-silicates, silicic acid, and insoluble organic matter, in the case of the mineral soils, in the case of peats and mucks, however, it might be partly assigned to the soluble organic acids and humus substances, and partly to organic insoluble acids and humus substances.

*Hence, the acidity or lime requirement of soils might be ascribed almost entirely to insoluble hydrated silicic acid, acid alumino-silicates, silica, and organic insoluble substances in the case of the mineral soils, and to organic soluble acids and humus substances, and organic insoluble acids and humus substances in the case of peats and mucks.*

Referring once more to the absorption curve of the mineral soils, it will be at once concluded that no exchange of bases takes place in the soil, when it is treated with $Ca(OH)_2$, until it is saturated with this base. Hence, while an exchange of bases may take place when the soil is treated with a neutral salt, such an exchange does not immediately occur when a free base is used.

Another very interesting phenomenon in connection with the absorption curve is the fact that the depression of the freezing point remains constant with the increase in the volume of water present. Thus, just before the soil is completely saturated or satisfied with $Ca(OH)_2$, the volume of water is increased in some cases almost twice and yet the lowering of the freezing point is the same. It appears that when the solution of the soil is very dilute the freezing point depression is not perceptibly affected even with considerable increase in the volume of water. Thus 2 grams of soil in 10 c. c. of water give a lowering of the freezing point of .010° C. Practically the same lowering of the freezing point is obtained when the same quantity of soil is treated with 20 c. c. of water. Even in pure salt solutions the freezing point depression remains almost constant with large dilutions, if the original solutions are very dilute. Thus, $MgSO_4$ at a certain concentration gave a depression of .010° C. Upon adding to 10 c. c. of this solution 10 c. c. of water, the depression changed to .008° C., or a difference of only .002° C. These results might be expected in the case of electrolytes.

Before concluding this part of the investigation, on the lime requirement of soils, a brief discussion should be devoted to the character of the reaction that is involved between the $Ca(OH)_2$ and the various soils, that is to say, is the reaction a chemical or a physical one? It should be at once stated that it appears to be both but the major part appears to be chemical. That probably it is not entirely physical may be mentioned the following facts: (1) The quantity of lime taken up by the various soils is too great to be accounted for entirely by surface phenomena; surface alone does not appear to be the predominant cause of the absorption because kaolin and quartz sand may be ground almost as fine as many of the clay loams here employed and yet their lime requirement is practically negligible. (2) The curves obtained are not adsorption curves; the adsorption curves are smooth equilibrium curves and consequently do not have such abrupt breaks as indicated in the foregoing curves. (3) There is no fundamental reason why the phenomenon cannot be chemical.

Lastly, the question may be asked, is it necessary and economical to add to the soil all the amount of lime according to the freezing point method, it requires? As previously declared, this question will ulti-

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mately have to be decided in the field, using the plant as indicator. All that is claimed is that the freezing point method, as a laboratory method, seems to indicate the true lime requirement of the soil. *By true lime requirement is meant the maximum specific activity that the different soils have for lime. In this maximum lime requirement there is included the lime that is necessary to neutralize any free soluble acids and acid salts, and the lime that the soil requires to satisfy its absorption-adsorption properties.* Now it is possible that this method indicates altogether too high lime requirement and when the plants are used as indicators it might be found that the plants can make just as good growth with smaller amounts as they can with the maximum. On the other hand it should be strongly emphasized that this method does not give altogether too abnormally high lime rebuirements. Indeed the maximum amounts indicated are quite in accord with some of the maximum applications that many soil authorities advise. Thus Hopkins[9] states: "It may be said, however, that 10 tons of ground limestone per acre would not only do no harm, but would probably produce somewhat larger crops than any lighter application. As much as 10 tons per acre has been applied on an experiment field in southern Illinois, and the crop yields on that field have been larger during the last three years than on any other experiment field in that area. Two to four tons per acre, however, have usually produced much benefit."

In a recent publication by Blair[10] the following statements are made in regard to the amounts of lime that might be applied to New Jersey soils: "With general farm crops on a loam to clay loam, 1,500 to 2,000 pounds of burned lime may be considered a moderate application. For alfalfa, 2,500 to 3,000 pounds could safely be used. For sands and sandy loams, 1,000 to 1,500 pounds would be a safe application. If the soil is known to be very acid or to contain a great deal of organic matter, a somewhat heavier application could be made," etc. Further on he says: "On wet land and muck lands as much as 5,000 to 10,000 pounds of lime may be required to correct the acidity."

It is evident, therefore, that the maximum lime requirements indicated by the freezing point method certainly appear to be in accordance with some of field practices.

### THE ABSORPTION OF NaOH, KOH, AND $NH_4OH$ BY SOILS.

In the last section the absorption of $Ca(OH)_2$ by different soils was considered. It will now be of great interest to ascertain the absorption by the same soils of other bases, namely KOH, NaOH, and $NH_4OH$. The absorption of these bases by the various soils represented in Table 5 was determined exactly in the same way as that of $Ca(OH)_2$ already considered. The solutions of these hydrates were diluted to such an extent that their freezing point depression was about the same as that of $Ca(OH)_2$—a little over .100° C. Their strength, however, was determined by titration and the necessary calculations made therefrom. Table 8 contains the amount of these bases taken up by the same soils used in the case of $Ca(OH)_2$. The quantity absorbed is expressed in number of c. c. of the hydrate per 2 grams of soil. For convenient and direct comparison the required $Ca(OH)_2$ by the same soils is also reproduced in this table.

(9) Soil Fertility and Permanent Agriculture, 1910, p. 173.
(10) Circular 54, New Jersey Agr. Expt. Sta., 1916.

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TABLE 8. THE ABSORPTION OF DIFFERENT HYDRATES BY VARIOUS SOILS.

| Kind of Soil. | No. c c. N/25 Hydrate absorbed by 2 grams of Soil. | | | |
|---|---|---|---|---|
| | $Ca(OH)_2$ | KOH | NaOH | $NH_4OH$ |
| 1. Heavy silt loam (gray) | 6.0 | 5.5 | 2.4 | 2.1 |
| 2. Heavy silt loam (black) | 9.0 | 5.5 | 4.8 | 2.6 |
| 3. Heavy clay loam (brown) | 8.5 | 5.5 | 5.0 | 2.4 |
| 4. Heavy silt loam (black) | 9.0 | 5.5 | 5.0 | 2.5 |
| 5. Light clay loam (black) | 6.0 | 2.5 | 2.4 | 1.2 |
| 6. Heavy silt loam (black) | 7.5 | 2.5 | 2.4 | 2.1 |
| 7. Light clay loam (gray) | 4.0 | 2.5 | 2.4 | 1.8 |
| 8. Heavy silt loam (gray) | 3.5 | 2.5 | 2.4 | 1.8 |
| 9. Light silt loam (black) | 3.5 | 2.5 | 1.8 | 0.9 |
| 10. Heavy silt loam (gray) | 3.5 | 2.5 | 1.8 | 1.2 |
| 11. Very light silt loam (black) | 3.5 | 2.5 | 1.8 | 1.2 |
| 12. Heavy sandy loam (black) | 6.0 | 2.5 | 2.4 | 1.5 |

The foregoing data reveal at once the remarkable fact that the amount of base taken up by any one soil differs markedly with the various bases. In other words, the soils do not absorb the various bases in chemically equivalent quantities. All soils take up $Ca(OH)_2$ in greatest quantity followed by KOH, NaOH, and $NH_4OH$ in order respectively. The various soils, also, do not absorb these various hydroxides in the same relative ratio.

Evidently, therefore, each soil possesses a specific reactivity for the different hydroxides.

It will now be of interest to ascertain whether a soil which is already satisfied with one base will still take up other bases. That is to say, if a soil is satisfied with the amount of $NH_4OH$ it requires, will it take up any more of $Ca(OH)_2$ and *vice versa*. To obtain information upon this question the problem was attacked in the following manner: The exact requirement of a soil for $Ca(OH)_2$, KOH, NaOH, and $NH_4OH$ was first ascertained in the usual manner. Then to this soil was added a little more than the true requirement of any one base and its freezing point depression determined. To this mixture was then added various quantities of another base until the depression began to change. If the depression began to change immediately upon the addition of a small amount of the second base then it was considered that the soil would not take up another base, i. e., cause it to disappear. Some of the data obtained are as follows:

2 gm. Soil No. 1 originally required 6 c. c. N/25 $Ca(OH)_2$ to cause change in depression, required only 1 c. c. after it received 2.5 c. c. N/25 $NH_4OH$.

2 gm. Soil No. 2 originally required 9 c. c. N/25 $Ca(OH)_2$ to cause change in depression, required only 1.5 c. c. after it received 3 c. c. N/25 $NH_4OH$.

2 gm. Soil No. 3 required 8.5 c. c. N/25 $Ca(OH)_2$ to cause change in the depression, required only 1.5 c. c. after it received 3 c. c. N/25 $NH_4OH$.

2 gm. Soil No. 1 originally required 5.5 c. c. N/25 KOH to cause change in the depression, required only 1 c. c. after it received 7 c. c. N/25 $Ca(OH)_2$.

2 gm. Soil No. 2 originally required 5.5 c. c. N/25 KOH to cause

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change in depression, required only 1 c. c. after it received 10 c. c. N/25 $Ca(OH)_2$.

2 gm. Soil No. 3 originally required 5.5 c. c. N/25 KOH to cause change in the depression, required only 1 c. c. after it received 9 c. c. N/25 $Ca(OH)_2$.

---

2 gm. Soil No. 1 originally required 6 c. c. N/25 $Ca(OH)_2$ to cause change in depression, required only 1 c. c. after it received 6 c. c. N/25 KOH.

2 gm. Soil No. 2 originally required 9 c. c. N/25 $Ca(OH)_2$ to cause change in depression, required only 1.5 c. c. after it received 6 c. c. N/25 KOH.

2 gm. Soil No. 3 originally required 8.5 c. c. N/25 $Ca(OH)_2$ to cause change in depression, required only 1.5 c. c. after it received 6 c. c. N/25 KOH.

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It becomes at once evident from the above tabulated data, therefore, that when a soil is saturated or satisfied with a particular base it will absorb very little if any of another base, even though the various bases are absorbed in non-equivalent amounts.

On the other hand, when a soil is only partly satisfied with one base it will take up a correspondingly large amount of another. Thus for instance, when a soil in 2 gm. portion required and received 3.5 c. c. N/25 KOH, the addition of only 1 c. c. N/25 $Ca(OH)_2$ caused a change in the depression. On the other hand, when only 2.5 c. c. N/25 KOH was added to this soil, it required 7 c. c. N/25 $Ca(OH)_2$ to cause a change in the depression. This was true in the case of all bases.

Just what is the true explanation of this unequal absorption of the various hydrates by the same kind of soils cannot be stated at this time. It is evident, however, that it follows some definite and significant laws. The problem is under special investigation and it is hoped the true explanation will be discovered.

Finally, it should be stated that this unequal absorption of the various hydrates, does not appear at present to be a point against the freezing point method, for determining the lime requirements of soils. On the contrary, it points to some phenomena which promise to be of significant theoretical interest and of important practical value.

### EFFECT OF ACIDS AND ACID SALTS UPON THE LIME REQUIREMENT OF SOILS.

Thus far the lime requirement of only natural untreated soils has been considered. The question will now be taken up of the effect of acids, acid salts, and neutral salts upon the lime requirement of soils. Since the data dealing with the acid and acid salt treatments illustrate certain fundamental principles which are necessary for a convenient and successful discussion of the data pertaining to the neutral salt treatments, they will be considered first.

The research on the effect of acids, and acid salts upon the lime requirement of soils consisted (1) of adding to 2 grams of soil various amounts of inorganic and organic acids, and inorganic acid salts and then determining its lime requirement; and (2) treating the soil with an excess of acid, then washing it with water, drying it in the air, and its lime requirement determined. In Table 9 there are presented the lime

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requirements of four different soils to which were added 10 c. c. of dilute (about N/100) HCl and dilute $Al_2(NO_3)_6$ in 2 gm. portion of soil, and also the requirement before treatment. These data will serve to typify the general results that were obtained by treating different soils with $H_2SO_4$, $HNO_3$, $H_2C_2O_4$, $AlCl_3$, $Fe(NO_3)_3$, etc. Table 10 contains the lime requirement of three different soils which were treated with an excess of dilute (N/100) HCl and then washed and dried.

TABLE 9. LIME REQUIREMENT OF SOILS TO WHICH WERE ADDED HCl AND $Al_2(NO_3)_6$.

| Soil. | HCl | | $Al_2(NO_3)_6$ | |
|---|---|---|---|---|
| | c.c. N/25 $Ca(OH)_2$ per 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ per gm. 2 soil. | Pounds CaO per acre. |
| Soil No. 1 before treatment | 6 | 6,730.8 | 6 | 6,730.8 |
| Soil No. 1 after treatment | 9.5 | 10,657.1 | 11 | 12,339.8 |
| Soil No. 2 before treatment | 9 | 10,096.2 | 9 | 10,096.2 |
| Soil No. 2 after treatment | 12.5 | 14,022.5 | 14.5 | 15,144.3 |
| Soil No. 3 before treatment | 8.5 | 9,535.3 | ..... | ..... |
| Soil No. 3 after treatment | 12 | 13,461.6 | ..... | ..... |
| Soil No. 4 before treatment | 4 | 4,487.2 | ..... | ..... |
| Soil No. 4 after treatment | 7.5 | 8,413.5 | ..... | ..... |

TABLE 10. LIME REQUIREMENT OF SOILS WHICH WERE TREATED WITH DILUTE HCl, WASHED, AND DRIED.

| Soil. | c.c. N/25 $Ca(OH)_2$ per 2 gm. soil. | Pounds CaO per acre. |
|---|---|---|
| Soil No. 1 before treatment | 6 | 6,730 8 |
| Soil No. 1 after treatment | 8 | 8,974.4 |
| Soil No. 2 before treatment | 9 | 10,096.2 |
| Soil No. 2 after treatment | 12 | 13,461.6 |
| Soil No. 3 before treatment | 8.5 | 9,525.3 |
| Soil No. 3 after treatment | 11 | 12,339.8 |

Considering first the data in Table 9 it will be immediately seen that the presence of 10 c. c. of either HCl or $Al_2(NO_3)_6$ in 2 gram portion of soil increased the lime requirement markedly. In the case of the HCl the increase over the untreated soils is about the same for all soils and amounts to about 3 c. c. N/25 $Ca(OH)_2$ or about 3,365 pounds CaO per acre. In the case of the $Al_2(NO_3)_6$ the magnitude of the increase is also approximately the same for all soils, and is about 5 c. c. of N/25 $Ca(OH)_2$ or 5,609 pounds CaO per acre.

In many experiments not here repeated the amounts of HCl or $Al_2(NO_3)_6$ added to 2 grams of soil were gradually increased from 0 to 10 c. c. by 2 c. c. portions. In every case the lime requirement of the soil increased directly with the amount of the acid or acid salt added.

The magnitude of the increase of the lime requirement of the soils appears to be approximately equal to the amount of lime required to neutralize the quantity of the acid or acid salt added. Thus, 10 c. c. of HCl of the strength employed required 2.8 c. c. of N/25 $Ca(OH)_2$ to be neutralized, while 10 c. c. of $Al_2(NO_3)_6$ solution took up nearly 6 c. c. of

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N/25 $Ca(OH)_2$ before a change in the color of the indicator occurred, using phenolphthalein as indicator. Practically identical results were obtained when the titration of the acid and acid salt was performed by the freezing point method.

Besides the HCl, and $Al_2(NO_3)_6$ other acids and acid salts were used, such as $HNO_3$, $H_2SO_4$, $AlCl_3$, $Fe(NO_3)_3$, etc. The data obtained coincide in principle with those above.

Referring now to Table 10, which contains the lime requirement of soils which were treated with HCl, then washed and dried, it will be observed that even this form of treatment increased the lime requirement. The increase in all soils is considerable.

In the case of the unwashed soils to which were added the acid or acid salts, the freezing point depression decreased with successive additions of $Ca(OH)_2$ until a point was reached, the neutralization-absorption point, and then it began to increase with further addition of the base. The data then plotted into an acid curve similar to that obtained when the acid and acid salt were titrated by the same hydrate. If there was present only a very small amount of the acid or acid salt, however, this acid curve could not be obtained, at least very pronouncedly, which would be naturally expected.

In the case of the soils, however, which were treated with an excess of acid and then washed for long time, the freezing point depression remained constant with successive additions of $Ca(OH)_2$ until a certain amount was added and then it began to increase. The results then plotted into an absorption curve similar to that of the untreated soils. The acid, or the substance which produced the acid curve, when the soils were treated with an acid, was evidently removed by washing with water, although an increase in the lime requirement still remained.

The foregoing general facts finally led to the desire to ascertain whether the strength of an acid changes when it is added to a soil which shows a large lime requirement by the freezing point method. For obtaining information upon this question the following experiment was performed. A soil which showed a lime requirement of about 10,000 pounds CaO per acre was treated with N/100 HCl in the ratio of 10 grams of soil to 50 c. c. of the acid. The mixture was stirred thoroughly for a few minutes and allowed to stand until the supernatant liquid was clear. Then about 15 c. c. of this supernatant liquid was taken, without filtering, and titrated with $Ca(OH)_2$, according to the freezing point method. To our surprise it was discovered that this supernatant liquid failed to give an acid curve, and the depression began to increase almost immediately upon adding about 2 c. c. N/25 $Ca(OH)_2$, indicating that the liquid contained very little if any acid. Some more of the supernatant liquid was taken out and tested for acidity with the litmus paper. True enough the liquid was neutral or very slightly acid. It was at once suggested that the acid or substance which gives the acid curve must be in the soil mass. All the remaining supernatant liquid then was poured off, the soil placed in the freezing point tube and titrated in the regular manner. The results gave an acid curve as usual. These results then tended to confirm the above suspicion that the acid must be in the soil and very little if any of it is diffused or represented in the solution which bathes the soil. Now if that is the case, it was reasoned, the blue litmus paper should turn red, when brought in intimate contact with the soil

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mass. This was tried and, true to the prediction, the blue litmus paper did turn red. The case then according to these series of experiments stood as follows: A soil in the natural condition showed a very high lime requirement according to the freezing point method, and gave an absorption curve. When this soil was treated with an excess of acid, the supernatant liquid was almost neutral both according to the freezing point method and the litmus paper test, while the sediment or soil mass, was acid to the litmus paper and gave an acid curve with the freezing point method. When this sediment was washed with water the acid or substance which yielded the acid curve and which was not equally represented in the supernatant liquid, disappeared.

The above series of experiments were repeated a great number of times using different soils, including some of the acid soils from the Rhode Island Experiment Station plots, and various inorganic acids, with exactly the same result.

To many soils were added as much as 60 c. c. N/100 HCl to 10 grams portions, without the supernatant liquid turning the blue litmus paper red, at least not immediately. Many of these litmus paper tests were repeated and verified by Prof. A. J. Patten and Prof. M. M. McCool.

After the foregoing series of experiments were completed there appeared an article by Rice[8] entitled "Soil Studies." In this paper Rice presents data on the basic exchange between soils and salt solutions as measured by the hydrogen ion concentration method. In connection with these studies he mentions a single experiment in which he shook two soils, which responded strongly to all the usual tests for soil acidity, with three times their quantity of N/100 $HNO_3$. He found, according to the hydrogen ion concentration method, that the strength of the acid added had been considerably reduced after contact with the soil. In conclusion he says: "Hence, even acid soils may neutralize acids to some extent. Whether or not, in addition, some of the acid was adsorbed by the soil was not determined."

*It may be accepted then as an established fact that when a soil, which takes up a large amount of lime, is treated with an excess of acid, up to a certain extent, the supernatant liquid may be neutral or only slightly acid, while the soil mass itself is strongly acid to litmus paper and gives an acid curve with the freezing point method.*

The interesting question now is, how may this phenomenon be explained? The question of neutralization of the supernatant liquid could be dispensed with at once by assuming that the bases of the soil neutralized the acid. But how about the acid remaining in the soil itself? It must be immediately declared that no satisfactory explanation can be offered at this time for the latter phenomenon. The problem is under special investigation and it is hoped to discover the true explanation. The following facts, however, should be recorded at this time:

The acid which remains in the soil mass and causes an acid curve to be obtained must be in solution, on two main grounds, (1) it can be removed very readily by washing with water and (2) it affects the freezing point depression, since on being neutralized with $Ca(OH)_2$ the depression of the soil is decreased, indicating that the acid combines with the base to form an insoluble compound and thereby is removed from solution, or to form a soluble salt which has a lower degree of dissociation

[8] J. Phy. Chem., 20, 214, (1916).

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than itself. But how and why should this soluble acid remain in the soil mass and not diffuse in the supernatant liquid which bathes the soil mass and thus be equally distributed? How is the law of equilibrium satisfied?

It was thought that if the soil held this soluble acid by some means—adsorption or occlusion—and did not allow it to diffuse equally into the supernatant liquid—which is contrary to the law of equilibrium—then there should be a difference of concentration between the supernatant liquid and the sediment. This point could be easily verified simply by determining the freezing point depression of the clear supernatant liquid and of the sediment. The experiment was performed but the results showed that there was no difference in the depression between the solution and the soil—indicating probably that the acid might not be free and in the liquid phase, or if it were, it had replaced or caused something else to go into solution, so that there was an equilibrium between the supernatant liquid and the soil mass, as far as concentration is concerned, but not in composition.

*Whatever the explanation should prove to be, this phenomenon certainly appears to be a most remarkable one.*

Having studied the effect of acids and acid salts upon the lime requirement of soils and the phenomenon relating thereto, it will now be of interest to know the results obtained with neutral salts.

### EFFECT OF SOLUBLE SALTS UPON THE LIME REQUIREMENT OF SOILS.

The effect of soluble salts upon the lime requirement of soils was studied in two different ways: (1) to 20 grams of soil were added 20 c. c. N/10 of a neutral salt solution, the soil allowed to dry in room temperature and its lime requirement determined according to the procedure already described; (2) to 2 grams of soil were added 2 c. c. of a N/10 salt solution, and 10 c. c. of water, and its lime requirement ascertained as usual. There were several soils used, ranging from very low to very high initial lime requirement. The salt solutions employed consisted of $NaNO_3$, $KNO_3$, $Ca(NO_3)_2$, KCL, $K_2SO_4$, $CaCl_2$, $MgSO_4$, $(NH_4)_2SO_4$, $NaC_2H_3O_2$, $K_2HPO_4$, and $CaH_4(PO_4)_2$ in N/10 strength. Since both methods gave essentially the same kind of results, and inasmuch as the second method is the most accurate, the results obtained by the second study will be presented here. These data are contained in Table 11.

An examination of the preceding data reveals clearly and decisively the following most important facts: (1) All the salts increased the lime requirement of the agricultural soils very markedly, but the neutral salts considerably more than the acid phosphate salts. Thus, in the case of Soil No. 2 the acid phosphate salts augmented the lime requirement by 1,121.8 pounds CaO per acre while the neutral salts increased the amount by 4,487.2 pounds; (2) All neutral salts increased the lime requirement of any one soil to the same magnitude. This was also true of the acid phosphate salts. Thus, in Soil No. 2 all the neutral salts caused an increase of 4,872 pounds CaO, and both phosphate salts, 1,121.8 pounds CaO; (3) In the case of quartz sand which originally took up no lime, none of the neutral salts caused it take up lime, but both of the phosphates did. This lime requirement, however, is due to the phosphate salts themselves and not to the quartz sand, as will subsequently be explained.

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TABLE 11. EFFECT OF SALTS UPON THE LIME REQUIREMENT OF SOILS.

| Number of soil. | $NaNO_3$ | | $KNO_3$ | | $Ca(NO_3)_2$ | | KCl | | $K_2SO_4$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. |
| No 1 untreated | 6 | 6,730.8 | 6 | 6,730.8 | 6 | 6,730.8 | 6 | 6,730.8 | 6 | 6,730.8 |
| No. 1 treated | 10 | 11,218.0 | 8 | 11,218.0 | 10 | 11,218.0 | 10 | 11,218.0 | 10 | 11,218.0 |
| No. 2 untreated | 9 | 10,096.2 | 9 | 10,096.2 | 9 | 10,096.2 | 9 | 10,096.2 | 9 | 10,096.2 |
| No. 2 treated | 13 | 14,583.4 | 13 | 14,583.4 | 13 | 14,583.4 | 13 | 14,583.4 | 13 | 14,583.4 |
| No. 3 untreated | 8.5 | 9,535.3 | 8.5 | 9,535.3 | 8.5 | 9,535.3 | 8.5 | 9,535.3 | 8.5 | 9,535.3 |
| No. 3 treated | 12.5 | 14,022.5 | 12.5 | 14,022.5 | 12.5 | 14,022.5 | 12.5 | 14,022.5 | 12.5 | 14,022.5 |
| No. 4 untreated | 1 | 1,121.8 | 1 | 1,121.8 | 1 | 1,121.8 | 1 | 1,121.8 | 1 | 1,121.8 |
| No. 4 treated | 4 | 4,487.2 | 4 | 4,487.2 | 4 | 4,487.2 | 4 | 4,487.2 | 4 | 4,487.2 |
| Quartz sand untreated | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Quartz sand treated | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |

| Number of soil. | $MgSO_4$ | | $(NH_4)_2SO_4$ | | $NaC_2H_3O_2$ | | $K_2HPO_4$ | | $CaH_4(PO_4)_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. |
| No 1 untreated | 6 | 6,730.8 | 6 | 6,730.8 | 6 | 6,730.8 | 6 | 6,730.8 | 6 | 6,730.8 |
| No. 1 treated | 10 | 11,218.0 | 10 | 11,218.0 | 10 | 11,218.0 | 9 | 10,096.2 | 9 | 10,096.2 |
| No. 2 untreated | 9 | 10,096.2 | 9 | 10,096.2 | 9 | 10,096.2 | 9 | 10,096.2 | 9 | 10,096.2 |
| No. 2 treated | 13 | 14,583.4 | 13 | 14,583.4 | 13 | 14,583.4 | 10 | 11,218.0 | 10 | 11,218.0 |
| No. 3 untreated | 8.5 | 9,535.3 | 8.5 | 9,535.3 | 8.5 | 9,535.3 | 8.5 | 9,535.3 | 8.5 | 9,535.3 |
| No. 3 treated | 12.5 | 14,022.5 | 12.5 | 14,022.5 | 12.5 | 14,022.5 | 10 | 11,218.0 | 10 | 11,218.0 |
| No. 4 untreated | 1 | 1,121.8 | 1 | 1,121.8 | 1 | 1,121.8 | 1 | 1,121.8 | 1 | 1,121.8 |
| No. 4 treated | 4 | 4,487.2 | 4 | 4,487.2 | 4 | 4,487.2 | 4 | 4,487.2 | 4 | 4,487.2 |
| Quartz sand untreated | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| Quartz sand treated | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 | 3,365.4 | 3 | 3,365.4 |

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Evidently, therefore, the application of soluble salts increases the lime requirements of soils quite markedly. The question now is, is this increase permanent or only temporary, and in either case how is it brought about?

To procure information upon these questions the following line of research was pursued: To 20 grams of soil were added 20 c. c. of any one of the salt solutions. The ratio of the soil to the solution and the strength of the solution were the same as above. The mixture was stirred and allowed to stand for about an hour. Then the mixture was poured upon a filter paper in a funnel and washed with water. The soil was allowed to dry in room temperature and its lime requirement was determined in the usual manner. The results obtained are detailed in Table 12.

TABLE 12. LIME REQUIREMENT OF SOILS WHICH WERE TREATED WITH SALT SOLUTIONS AND THEN WASHED.

| Soil. | $NaNO_3$ | | $K_2SO_4$ | |
|---|---|---|---|---|
| | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. | c.c. N/25 $Ca(OH)_2$ absorbed by 2 gm. soil. | Pounds CaO per acre. |
| Soil No. 1 untreated | 6 | 6,730.8 | 6 | 6,730.8 |
| Soil No. 1 treated | 6 | 6,730.8 | 6 | 6,730.8 |
| Soil No. 2 untreated | 9 | 10,096.2 | 9 | 10,096.2 |
| Soil No. 2 treated | 9 | 10,096.2 | 9 | 10,096.2 |
| Soil No. 3 untreated | 8.5 | 9,535.3 | 8.5 | 9,535.3 |
| Soil No. 3 treated | 8.0 | 8.974.4 | 8.5 | 8,974.4 |

The data in the above table are highly interesting and very significant. They show that the soils which were treated with various salt solutions and then washed, have practically the same lime requirement as that before treatment. In other words, the substance which increases their lime requirement when they are treated with the soluble salts disappears upon washing, and they come back to their original lime requirement.

*These data then go to prove three main facts,* (1) *The substance which caused an increase in the lime requirement of the soil upon being treated with the soluble salts was soluble or in solution and was readily carried away by washing,* (2) *The treatment did not produce any permanent change in the soil, either chemical or physical and consequently* (3) *the increase in lime requirement brought about by the application of soluble salts was only temporary and not permanent.*

Now what is the nature of the substance which is produced in the soil by the salts, and is readily soluble or in solution, that causes the increase in the lime requirement. Before attempting to answer this question it is essential to consider first the type of curve that the soils containing the substance, i. e., the soils which are treated with the salt solution and not washed, will yield upon being titrated with $Ca(OH)_2$ according to the freezing point method. The data pertaining to this phase of the investigation are contained in Table 13 and graphically represented in figures 7a, 7b, 7c and 7d. Only a few typical examples are here submitted.

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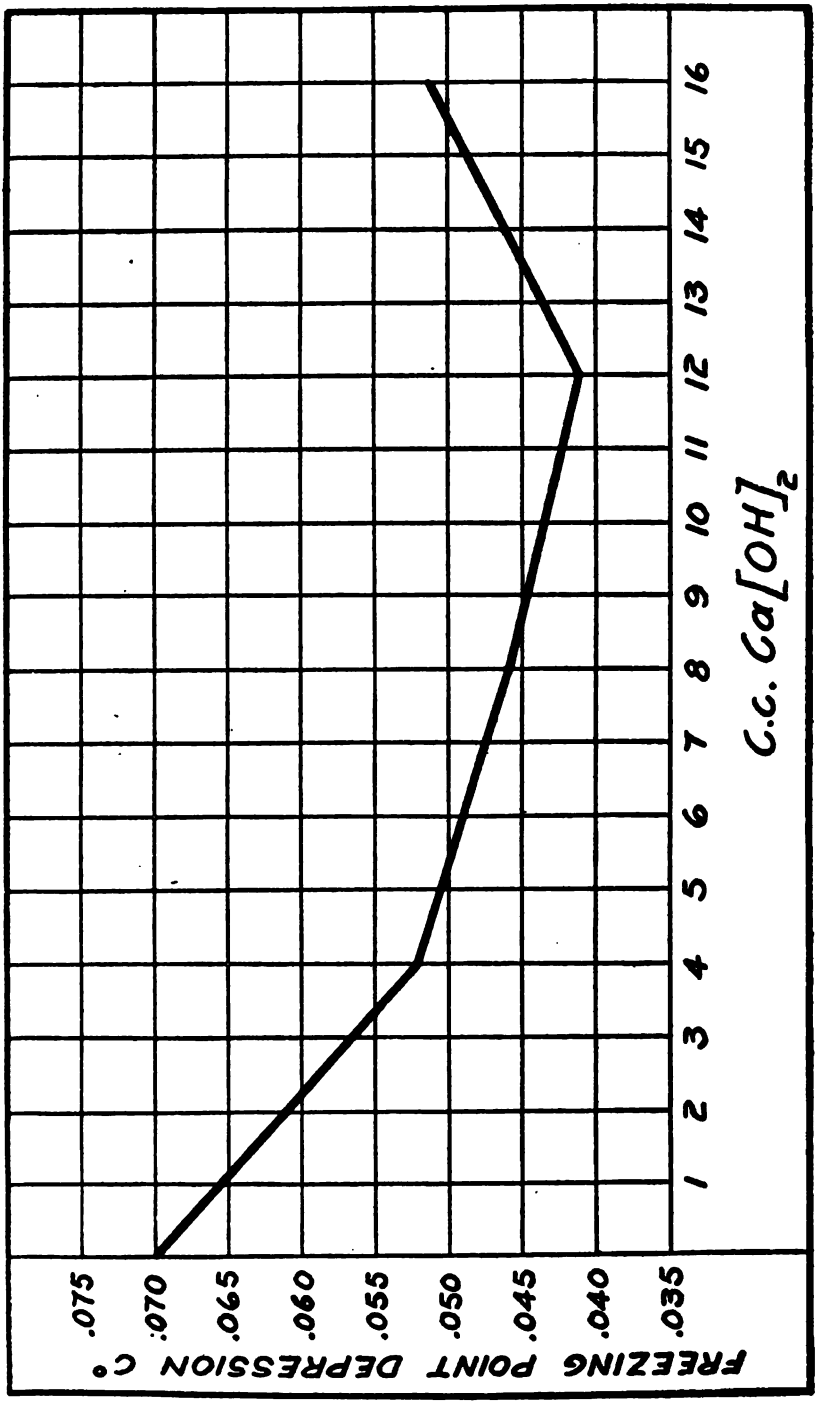


FIGURE 18. Curve showing the decrease in the depression of soil, which was previously treated with $NaNO_3$, by the addition of $Ca(OH)_2$ down to a certain point and then the increase with the further addition of $Ca(OH)_2$.

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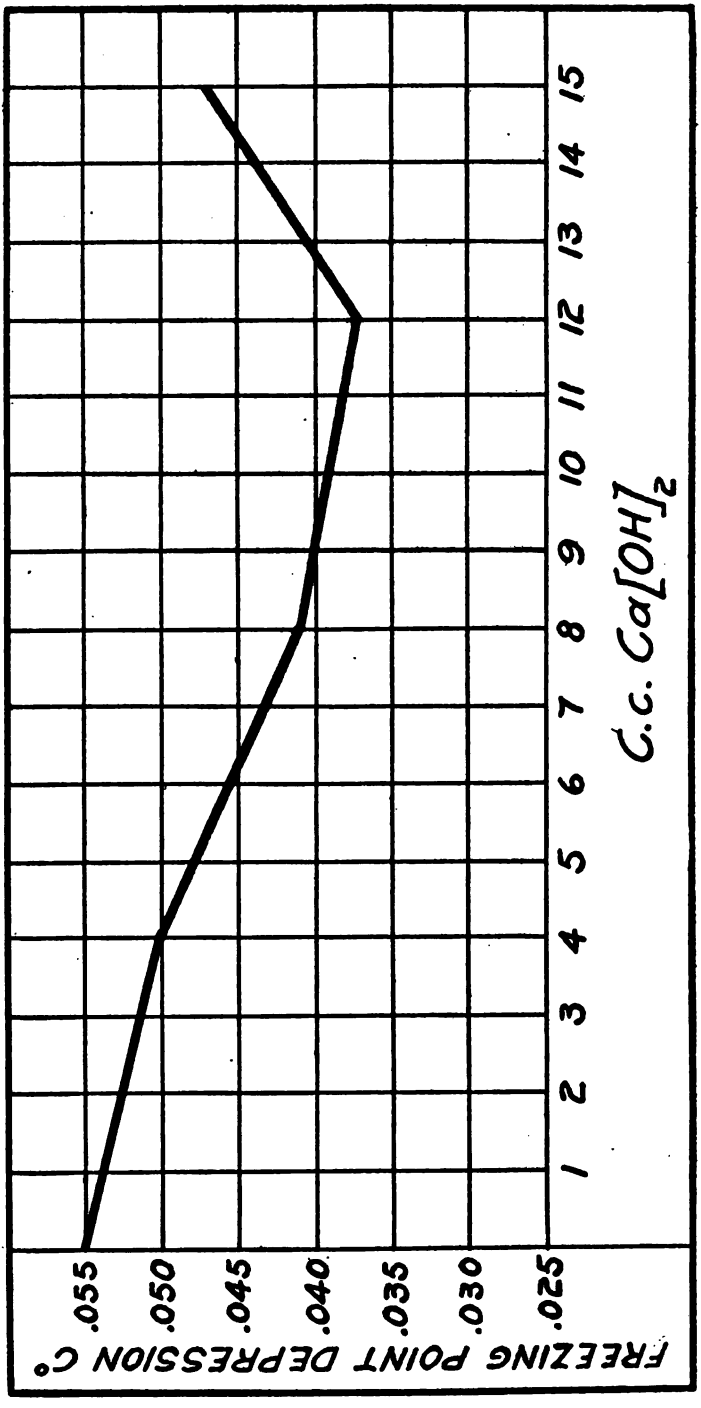


FIGURE 7b. Curve showing the decrease of the depression of soil, which was previously treated with $CaNO_3$, by the addition of $Ca(OH)_2$ down to a certain point and then the increase with the further addition of $Ca(OH)_2$.

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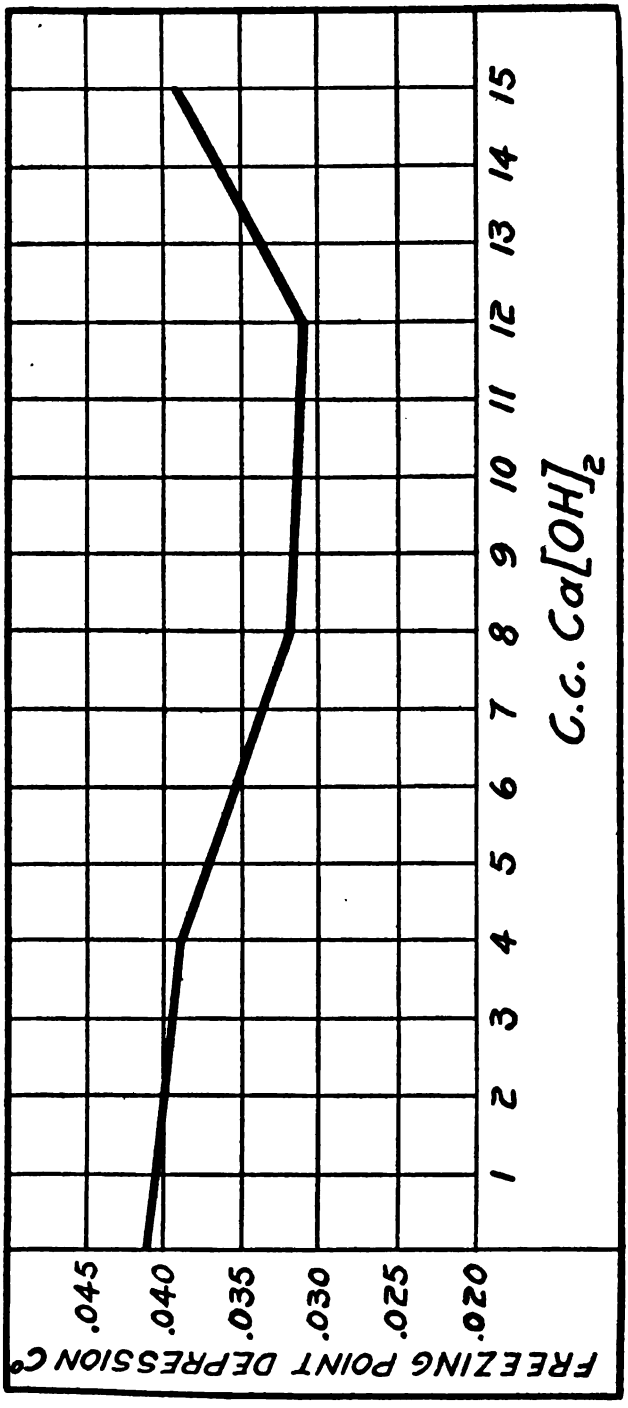


FIGURE 7c. Curve showing the decrease in the depression of soil, which was previously treated with $K_2SO_4$, by the addition of $Ca(OH)_2$; down to a certain point and then the increase with the further addition of $Ca(OH)_2$.

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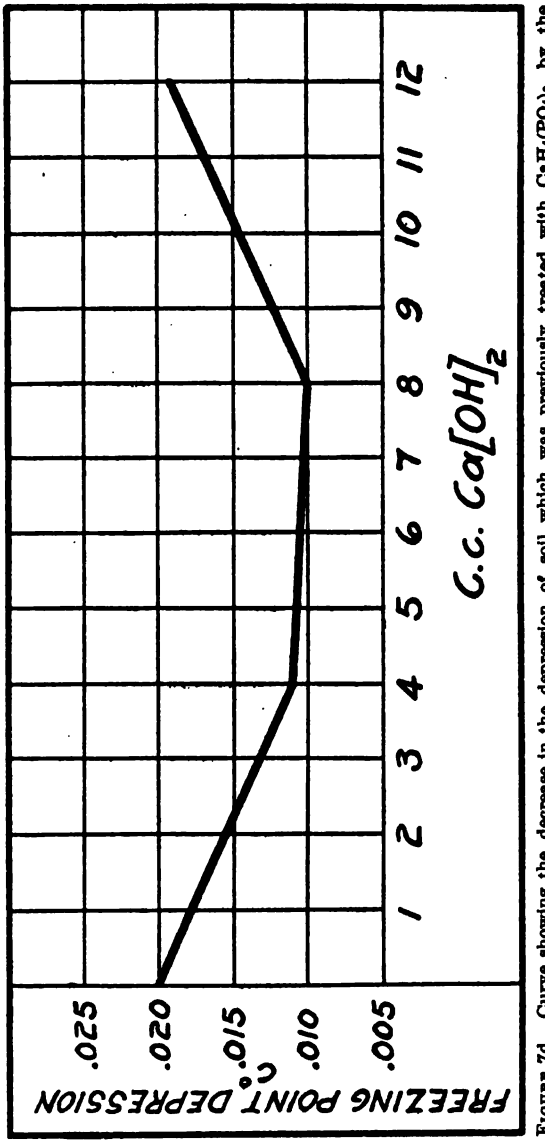


FIGURE 7d. Curve showing the decrease in the depression of soil which was previously treated with $CaH_4(PO_4)_2$, by the addition of $Ca(OH)_2$ down to a certain point and then the increase with the further addition of Ca(OH)

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TABLE 13. FREEZING POINT DEPRESSION OF SOILS WHICH WERE TREATED WITH SALT SOLUTIONS AND TITRATED WITH $Ca(OH)_2$.

| Reagents. | Depression. |
|---|---|
| 2 gm. soil plus 2 c.c. N/10 $NaNO_3$ plus 10 c.c. water | .070°C |
| plus 4 c.c. $Ca(OH)_2$ | .052 |
| plus 4 c.c. $Ca(OH)_2$ | .046 |
| plus 4 c.c. $Ca(OH)_2$ | .041 |
| plus 4 c.c. $Ca(OH)_2$ | .051 |
| 2 gm. soil plus 2 c.c. n/10 $CaNO_3$ plus 10 c.c. water | .056°C |
| plus 4 c.c. $Ca(OH)_2$ | .050 |
| plus 4 c.c. $Ca(OH)_2$ | .041 |
| plus 4 c.c. $Ca(OH)_2$ | .037 |
| plus 3 c.c. $Ca(OH)_2$ | .047 |
| 2 gm. soil plus 2 c.c. n/10 $K_2SO_4$ plus 10 c.c. water | .041°C |
| plus 4 c.c. $Ca(OH)_2$ | .039 |
| plus 4 c.c. $Ca(OH)_2$ | .032 |
| plus 4 c.c. $Ca(OH)_2$ | .031 |
| plus 3 c.c. $Ca(OH)_2$ | .039 |
| 2 gm. soil plus 2 c.c. n/10 $CaHPO_4$ plus 10 c.c. water | .020°C |
| plus 4 c.c. $Ca(OH)_2$ | .011 |
| plus 4 c.c. $Ca(OH)_2$ | .010 |
| plus 4 c.c. $Ca(OH)_2$ | .019 |

It is at once seen that the general type of numerical data and curve yielded by the soils which were treated with soluble salts is almost exactly the same as that obtained when a pure acid or acid salt or a soil treated with an acid or acid salt is titrated with $Ca(OH)_2$. The irresistable and logical conclusion immediately appears to be, therefore, that the substance produced in the soils when they are treated with different soluble salts, consists either of a soluble free acid or an acid salt. This conclusion appears to be supported by what is already known concerning the reaction between a salt solution and the soil. According to the adsorption and chemical theories, when a soil reacts with a salt, the base of the salt is taken up by the soil and leaves in solution a free acid, or the base taken up releases a weaker base such as aluminum, which combines with the acid radical of the salt to form an acid salt.

Hence, the answer to the above question, what is the nature of the substance produced in the soil by the application of soluble salts, which increases the lime requirement, *appears to be that it consists either of a free acid or an acid salt, but most likely the latter.*

At this point it should be stated that the above explanation as to the cause of the acid curve, applies only to the neutral salts and not to the acid phosphate salts, $CaH_4(PO_4)_2$ and $K_2HPO_4$. These phosphate salts are acid salts and will produce the acid curve even before they are applied to the soil. The acid curve produced after they are applied to the soil is doubtless due to the same compounds and not necessarily to some other acid or acid salt formed.

It should also be recorded that the acid curve will be obtained upon the application of soluble salts only when the soil shows a lime requirement, by the freezing point method. If the soil shows no lime requirement, such as the quartz sand, the acid curve will not be obtained, except in the case of the phosphate salts. The same is true when a soil is alkaline or already saturated with a base. If a soil, however, takes up only a very small amount of lime, the acid curve will be very unpronounced.

Not all neutral salts give in the soil an acid curve of the same degree of pronouncement. That is to say the amount of decrease in the depression is not the same for all neutral salts. Thus $Ca(NO_3)_2$, $NaNO_3$,

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$KNO_3$, KCl, and $CaCl_2$ give a far more pronounced acid curve than $K_2SO_4$, $MgSO_4$, $(NH_4)_2SO_4$, and $NaH_2C_2O_2$. This, however, is naturally to be expected since the products formed by the reaction between the $Ca(OH)_2$ and the acid or acid salt of these neutral salts possess different degrees of dissociation or solubility.

In considering the results on the effect of acids upon the lime requirement of soils, it was seen that when a soil, which showed a large lime requirement was treated with an excess of dilute acid, the supernatant liquid failed to give the acid curve, while the sediment did, but when the sediment was washed, then the acid curve could no longer be obtained. The natural and logical question now rises, do similar phenomena also occur in the case of the salt solutions?

The answer to this question was obtained by attacking the problem in the same manner as before, namely, to several different soils, which showed a high lime requirement, were added different salt solutions in the ratio of 10 grams of soil to 50 c. c. of the solution of N/10 strength. The mixture was stirred thoroughly for a few minutes, then allowed to stand for about an hour until the supernatant liquid became clear. Then some of the supernatant liquid was poured into the freezing tube without filtering, and titrated with $Ca(OH)_2$ in the usual manner. It was found that the depression began to increase immediately upon adding about 2 c. c. of $Ca(OH)_2$, indicating that the supernatant liquid failed to give an acid curve. Then the remainder of the solution was poured out and the sediment was placed in the freezing tube and titrated with $Ca(OH)_2$. It was found that the freezing point depression decreased with the increased addition of $Ca(OH)_2$ until a certain point was reached and then commenced to rise. The results then plotted into an acid curve, and proved that the soil contained an acid or acid salt or some substance which was not equally or proportionally represented in the supernatant solution. In another sample of soil similarly treated, the sediment was washed with water and then titrated. In this case the freezing point depression remained constant up to a certain point and then began to rise. The results, then plotted into an absorption curve, and proved that the substance which gave the acid curve above was washed away with water.

*These experiments were repeated with many of the neutral salts using different soils, and in every case the results were the same, namely the supernatant liquid failed to give an acid curve while the sediment did, but when the sediment was washed then it no longer yielded an acid curve.*

These results then agree perfectly with those obtained with acids, and whatever is the explanation for the one case is true also for the other.

Since no mineral soil out of a number of 80 tested for lime requirement in their natural condition gave an acid curve but only an absorption curve, and inasmuch as the free acid and acid salt produced in these soils when they were treated with neutral salts or acids and acid salts, were carried away by washing and the soils then gave an absorption curve, it seems safe and logical to conclude that the presence of soluble acids, or acid salts in the mineral soils under field conditions is only temporary and probably never permanent. The acidity or lime absorption of the mineral soils, therefore, is probably due mainly, if not entirely, to the insoluble acids of the soil, the silicic acid, acid alumino-silicate, and

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silica, and perhaps to the insoluble organic matter. There is probably then practically no active acidity in the mineral soils, but only negative. Exceptions to this general statement are probably very few.

In the peats and mucks, however, the formation of the organic acids is probably quite rapid, and consequently these soils may contain permanent active acidity, as well as permanent negative acidity.

*One more point before concluding. If it is true—which is beyond any doubt—that when a soil is treated with an excess of acid, acid salt and neutral salt, the supernatant liquid contains very little acid or acid salt, while the soil mass itself retains a large amount of the acid or acid salt (or a substance which greatly increases the lime requirement), then the question rises, can any of the present soil acidity methods which employ neutral salts and use only the supernatant liquid, give the true lime requirement of the soil? This is indeed a question of great and fundamental importance and must not be ignored.*

NOTE: After the foregoing report was completed and submitted for publication there were received from the Rhode Island Experiment Station samples of twelve different soils, with a request from Mr. F. R. Pember to determine their lime requirement by the freezing point method. As the cultural history of these soils is known, their results on lime requirement are of high interest and great significance from the standpoint of the reliability and value of the freezing point method. The data obtained are detailed in the following table:

TABLE 14. LIME REQUIREMENT OF SOILS.

| Number of soil. | Pounds CaO per 2,000,000 pounds soil. |
|---|---|
| 1 | 10,096.2 |
| 2 | 6,730.8 |
| 3 | 15,705.2 |
| 4 | 27,000 |
| 5 | 15,705.2 |
| 6 | 8,974.4 |
| 7 | 560.9 |
| 8 | 560.9 |
| 200 | 8,413.5 |
| 201 | 8,413.5 |
| 202 | 6,730.8 |
| 203 | 6,730.8 |

It will be at once seen that the different soils took up entirely different amounts of lime; the quantity ranging from 560.9 pounds CaO per acre in the case of soils No. 7 and 8 to 27,000 pounds in the case of soil No. 4.

Soils No. 7 and 8 are sand, while all the other soils may be classed as very fine sandy loam. Since the texture of the latter soils is more or less the same, their different lime requirement must be due to the difference in the cultural treatment they have received. In other words, the great variation in the lime requirement of these soils, which originally probably belonged to the same series and type, is caused by the different cultural treatment they have received. Indeed, their cultural history, as indicated by the following communication from Mr. Pember, proves such to be the case:

"The soil of samples No. 1 and 3 came from field plat No. 23 in the spring of 1915 and was stored under greenhouse conditions until used.

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For full description of the growth of plants in the field on this soil, see Rhode Island Bulletin No. 160. Before growing barley in this soil the past winter, a liberal amount of K N and P was added to the soil. No. 2 received in addition C. P. $CaCO_3$ at the rate of 3 tons per acre, area basis. No. 3 received in addition a solution of $H_3PO_4$.

Soils No. 4 to 6 came from the benches in the greenhouse where the carnations are growing at the present time. All had received stable manure for the last three years and Nos. 4 and 5 have had the stable manure supplemented with large amounts of chemical manure. Nos. 7 and 8 are sand in which carnations are growing for the third season and the chemical manures added during the three years have exceeded the amount added to Nos. 4 or 5.

Soils No. 200 and 201 came from the vetch-clover area of the corn acre this spring but the samples were taken about four weeks apart. Nos. 202 and 203 came from the fallow area of this same field at the same time as No. 200 and 201. We speak of the "corn acre" because this field has been planted to corn each year for about twenty years. One section of the field has crimson clover and winter vetch sown at the last cultivation of the corn, while on what we term the fallow section, the corn receives clean cultivation throughout the season, and the section remains fallow the rest of the year.

Carnation plants put into Nos. 4 and 5 last fall failed to make much growth, and have done very poorly since early winter in sand No. 8. In No. 2 the growth of the barley was much improved by the addition of $CaCO_3$ while the addition of $H_3PO_4$ depressed the growth only 19%"

The values of the lime requirement of the different soils as shown in table 14 are of very great significance in the light of the facts contained in the above communication. According to Mr. Pember's letter, for instance, soils No. 1, 2 and 3 came from the same plot and consequently they should be quite uniform texturely. They all received liberal applications of K P and N. Soil No. 2, however, received in addition, 3 tons of $CaCO_3$. This soil, therefore, shows much less lime requirement than soil No. 1 which may be taken as a check. Soil No. 3, received, in addition to K P and N, also a solution of $H_3PO_4$. This soil shows a far greater lime requirement than the other two soils.

Soils No. 4, 5 and 6 received stable manure, and soils No. 4 and 5 received in addition large amounts of chemical fertilizers. The lime requirement of soils No. 4 and 5 which received the chemical fertilizers is much greater than that of soil No. 6.

Soils No. 7 and 8 are almost quartz sand and although they were treated with large applications of fertilizers, their lime requirement is very small, since quartz sand usually takes up very little, if any, lime.

Soils No. 200 and 203 came from the same field but soils No. 200 and 201 came from the "corn acre" and Nos. 202 and 203 from the fallow area. The former two soils show a greater lime requirement than the two latter soils.

The failure of the carnations to grow in soils No. 4, 5 and 8 is not due entirely to the lack of lime, but to the tremendous concentration of the solution of these soils. These soils have received, evidently, such large applications of chemical manures that the concentration of their solution is really tremendous. Thus, at a very high moisture content, almost at the point of saturation, these soils gave a depression of over

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.600° C., which is about 30 times as great as that of normal soils. At a lower moisture content this depression would be much greater. Now, when it is considered that the depression of the cell sap of young cereal plants amounts to a little less than 1.00° C., it becomes at once evident that the failure of the carnations to grow in these soils is undoubtedly due to the great concentration of the soil solution.

The results on the lime requirement of these Rhode Island soils seem to afford a most excellent confirmation of the previous laboratory results and a definite proof that the lime requirement value, as indicated by the freezing point method, is due to a definite factor and this factor seems to be somewhat related to crop growth.

## SUMMARY.

In the present paper there is presented the freezing point method as a new method for determining the lime requirement of the soils and possibly the nature of their acidity.

The method consists of adding to 2 grams of soil 10 c. c. of water and determining the lowering of the freezing point. Then to this mixture are added various amounts of $Ca(OH)_2$ until there occurs a change in the magnitude or direction of the freezing point depression.

The method is based upon the following principles for indicating the lime requirement of soils and the nature of their acidity: (1) If a soil contains a free soluble acid or acid salt its freezing point depression decreases upon adding to it various quantities of $Ca(OH)_2$ until a certain point is reached and then it begins to increase with further addition of $Ca(OH)_2$. This point is considered to be the point of neutralization of the acid or acid salt and of the saturization of the soil for lime. The results plot into a type of curve which is designated as an acid curve. (2) If a soil, however, contains neither a soluble acid nor an acid salt but possesses an absorptive power for lime, due probably to the unsatisfied silicate compounds and organic matter, the freezing point depression remains constant as more and more of $Ca(OH)_2$ is added to the soil until a critical point is reached and then it commences to rise with further addition of $Ca(OH)_2$. The critical point is considered to be the saturation of the soil for lime. The results plot into a type of curve which is designated as an absorption curve. (3) If the soil contains neither a free soluble acid or acid salt, nor an absorptive power for lime, i. e., it is already alkaline and saturated with bases, then the freezing point depression starts to rise almost immediately upon the addition of a small amount of $Ca(OH)_2$. The curve obtained from these results is named the alkaline or no-lime-absorption curve.

The method is simple, accurate, extremely rapid, entirely different in principle from that of any other method now in vogue, and appears to be very promising as it affords a direct means of studying the problem of soil acidity.

The lime requirement of over 95 different soils in their natural state was determined by this method. The results show that the amount of lime taken up by these soils varies greatly.

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The freezing point method gives much higher lime requirement than the Veitch method. It appears that the former method probably gives the true maximum lime requirement of soils. By true maximum lime requirement is meant the total amount of lime required to neutralize any soluble acids and acid salts of soils and to satisfy their absorption-adsorption properties for lime.

All the mineral soils tested gave an absorption curve, indicating probably that they did not contain a soluble acid or acid salt.

The absorption curve of the mineral soils signifies that the $Ca(OH)_2$ is taken out of solution and is rendered inactive as far as the freezing point depression is concerned. The substances which accomplish this are in the solid phase. A critical consideration of the soil mass as well as many experimental evidences seem to indicate that these solid substances, in the case of the mineral soils, consist mainly of unsaturated silicic acid, silica, acid alumino-silicates, and perhaps insoluble organic matter, probably in the colloidal, hydrated form.

The absorption curve also indicates that there is no basic exchange in soils, when a hydrate is employed, until the soil is satisfied or saturated with the base.

Only a few peats were tested and most of them gave an acid curve, indicating probably that most of them contained free acids.

The same kind of soils took up $Ca(OH)_2$, KOH, NaOH, and $NH_4OH$ in non-chemically equivalent amounts. As a very general rule each soil tended to show a specific reactivity for these different hydrates. This unequal absorption does not appear to be against the value of the freezing point method.

When a soil was satisfied with one base it took up very little if any of another base, or if it did, it released a corresponding amount of the one with which it was already saturated.

On the other hand, when a soil was only partly satisfied with one base it absorbed a corresponding quantity of another.

The addition of acids and acid salts increased the lime requirement of soils. The magnitude of the increase was approximately equal to the amount of lime required to neutralize the quantity of the acid or acid salt added. The results plotted into an acid curve.

When a soil was treated with an excess of acid and then washed, the lime requirement was also increased, but the results plotted into an absorption curve.

When a soil, which showed a high lime requirement, was treated with an excess of acid, the clear supernatant liquid failed to give an acid curve, indicating that it contained very little if any acid. The litmus paper test showed that it was very nearly neutral. The sediment, however, gave an acid curve, signifying that it contained a considerable amount of acid. It turned the blue litmus paper red. When this sediment was washed with water, however, the acid curve could no longer be obtained, showing that the acid was washed away.

All soluble salts increased the lime requirement of soils, but the magnitude of increase was greater in the case of the neutral salts than of the acid phosphate salts. All of the former salts employed augmented the lime absorption of any one soil to the same degree. The same was true of all the latter salts. The increase, however, in both cases was only temporary, as after washing with water the soils possessed the same lime

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requirement as before treatment. Before washing, the soils gave the acid curve with all the salts, but after washing they all yielded the absorption curve, proving that the substance which caused an increase in the lime requirement and produced the acid curve, was washed away.

The same phenomenon was observed in the case of the salt solutions, as in the acids, namely, when a soil which showed a high lime requirement was treated with an excess of salt solution, the supernatant liquid failed to give an acid curve but the sediment did, but when the sediment was washed with water, then it no longer gave the acid curve, but the absorption curve. These phenomena are very remarkable and exceedingly significant.

Since no mineral soil out of a great number tested gave an acid curve but only an absorption curve, and inasmuch as the free acid, and acid salt produced in these soils when they were treated with neutral salts, or acid and acid salts, were carried away by washing and the soils then gave an absorption curve, the conclusion seems to be that the presence of soluble acids, or acid salts, in the mineral soils under favorable natural conditions is only temporary, if ever present, and never permanent. The acidity or lime requirement of soils, therefore, seems to be due mainly to the insoluble acids of the soil, the silicic acid, silica, acid alumino-silicates, and perhaps to the insoluble organic matter. There appears to be then practically no active acidity in the mineral soils, but only negative. Exceptions to these general statements are probably very few.

In the peats and mucks, however, the formation of organic acids is probably quite rapid, and consequently these soils, as indicated by the data, may contain permanent active acidity as well as permanent negative acidity.

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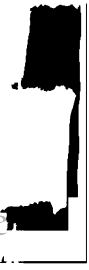
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